Study and Analysis of Fuel Consumption and Emissions Reductions for Heavy-Duty Diesel Trucks

Final Report

Prepared for:

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Prepared by:

North Central Texas Council of Governments
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1 Executive Summary

The North Central Texas Council of Governments (NCTCOG) conducted an in-use demonstration project to evaluate the impact of SmartWay^{SM} technologies on fuel efficiency among Class 8 heavy-duty trucks. The project was intended to quantify changes in fuel economy as measured in miles per gallon (MPG), and also emissions reductions, in order to better inform the industry of the benefits of utilizing SmartWay technologies. It is hoped that this quantification will prompt additional investment across the long-haul trucking industry.

Through a competitive process, NCTCOG selected two trucking fleets, Roehl Transport, Inc. (Roehl) and Sagebrush Logistics, LLC, (Sagebrush), as partners for this study. A total of 41 trucks were evaluated, representing four different configurations of SmartWay technologies. Data was collected for all trucks for at least a 12-month period, and NCTCOG evaluated differences between control data and test data among the truck fleets. Analysis was conducted through the following phases:

- Differences in fuel economy and emissions between Roehl test fleet and Roehl control fleet (technologies installed: auxiliary power unit, low viscosity lubricants, and crankcase filters),
- Differences in fuel economy and emissions between control and test conditions for Sagebrush Truck Group A (technologies installed: auxiliary power unit, single-wide tires, and diesel oxidation catalyst),
- Differences in fuel economy and emissions between control and test conditions for Sagebrush Truck Group B (technologies installed: auxiliary power unit and diesel oxidation catalyst),
- Differences in fuel economy and emissions between control and test conditions for Sagebrush Truck Group C (technologies installed: auxiliary power unit),
- Differences in fuel economy and emissions between control conditions for all Sagebrush trucks and test conditions for Groups A, B, and C individually, and
- Differences in fuel economy and emissions between control and test conditions for all Sagebrush trucks.

Statistical analysis revealed no significant change in fuel economy among Roehl trucks, but did reveal a significant difference in speed between the test and control fleets. This and other operational factors, such as differences in routes and driver behavior, create difficulty in drawing conclusions regarding the SmartWay technologies' impact on fuel economy based upon the data available. However, use of APUs decreased the incidence and extent of extended idle time among the test fleet, which resulted in emissions reductions of 102.08 pounds nitrogen oxides (NO_x), 2.78 pounds particulate matter (PM), and 6,091.38 pounds carbon dioxide (CO_2) for these six trucks over the study period.

Among Sagebrush trucks, analysis revealed a consistent improvement in fuel economy under test conditions as compared to control conditions. Truck Group A,, which contained the most SmartWay technologies bundled in an upgrade kit, exhibited an approximately 11 percent improvement in MPG. Although operational factors may also have influenced the change in fuel economy under test conditions, differences in observed increase in MPG among the various truck groups suggest that some improvement is attributable directly to the SmartWay technologies. Across the entire Sagebrush truck group, the increase in fuel economy is estimated to reduce emissions rates of NO_x, PM, and CO_2 by approximately seven percent.

Many challenges existed in this study, including numerous externalities related to vehicle operations. These variables make it difficult to isolate the impact of SmartWay technologies on fuel economy. The unpredictability of the trucking industry exacerbates these challenges, and also led to significant departures from the original study design. Despite these obstacles, however, the study supports the finding that the use of SmartWay technologies, particularly when bundled as a kit, is an effective tool for improving fleet efficiency, reducing emissions, and increasing fuel economy.

2 Introduction

2.1 Problem Definition and Background

The United States (U.S.) Environmental Protection Agency (EPA) established the SmartWay Transport Partnership (SmartWay) in 2004 as a voluntary partnership with the freight industry to reduce emissions and fuel consumption among the goods movement sector. Through this program, EPA promotes various strategies designed to increase energy efficiency and reduce fuel and maintenance costs for freight companies.

One strategy is to incorporate technologies on heavy-duty diesel trucks that reduce fuel use and emissions. At the time this study began, EPA had recommended use of the following technologies in the SmartWay program: single-wide tires, automatic tire inflation, advanced trailer aerodynamics, NO_x reflash, lube viscosity, mobile idle reduction technologies and emission control technologies such as diesel oxidation catalysts, crankcase filters and diesel particulate filters. EPA anticipates that these technologies may be most effective if utilized together in a bundled configuration called a SmartWay "upgrade kit".

Implementation of these technologies by trucking companies has often been discouraged by up-front capital costs and access to affordable financing. In order to purchase these technologies, truck owners need confirmation of fuel cost savings to assure a return for their investment. Likewise, financial institutions are more willing to offer loan packages for technologies with documented financial savings. In addition, grant programs and other financial assistance have typically not focused on long-haul freight emissions, as long-haul trucks cross jurisdictional boundaries.

This study was designed to evaluate fuel savings and emissions reductions gained from use of these technologies under real operating conditions, with the intent of prompting greater adoption and use across the industry as benefits were documented and quantified. NCTCOG partnered with EPA to provide financial assistance for long-haul fleets to purchase and install approved SmartWay technologies as an upgrade kit. The private sector fleets subsequently submitted in-use performance data for a minimum of 12 months to evaluate the effectiveness and benefits of using the SmartWay upgrade kit.

2.2 Participants

Participants in this study included the EPA, NCTCOG, and private sector trucking companies who were selected by NCTCOG through a competitive Call for Projects (CFP). These companies entered into contracts with NCTCOG as subrecipients of EPA funds which were used to offset up to 50 percent of the purchase and installation cost of approved fuel-saving and idle-reduction technologies, and 100 percent of purchase and installation costs for emission-reduction devices. To maximize the number of trucks which could be outfitted with upgrade kits through this study, NCTCOG contacted numerous vendors of approved SmartWay technologies to negotiate discounts for items purchased for this demonstration project and provided information about these discounts to CFP applicants. The trucking companies were responsible for technology procurement and installation and subsequently for the collection and submission of in-use performance data for a minimum of a 12-month study period. At the end of the study period, all grant-funded technologies would be fully vested with the fleet participants. The following criteria were used to determine eligible trucking companies:

- Based in a nonattainment or maintenance area, and/or operate in the Dallas-Fort Worth (DFW) Metroplex or near the U.S.-Mexico border,
- Willingness to contribute at least 50 percent of the capital costs towards fuel-saving and mobile idle-reduction technologies,
- Willingness to maintain a SmartWay tractor-trailer combination throughout the duration of the study period, or create trailer pools whereby a SmartWay trailer is always available at the drop-off or pick-up location,
- Ability to maintain and track fuel economy in a consistent and reliable manner,
- Ability to travel consistent, dedicated routes over long distances,
- Ownership of trucks already equipped with SmartWay technologies,
- Willingness to include fuel economy data from a sampling of trucks traveling similar routes as the test vehicles, but which are not equipped with SmartWay technologies to provide a baseline for comparison,
- Willingness to provide other project data such as fuel logs, fuel receipts, truck/engine information and characterization of operations, and
- Commitments to operating, maintaining, and supporting SmartWay upgrade kit technology.

Through this CFP, NCTCOG selected Roehl Transport, Inc. (Roehl) and Sagebrush Logistics, LLC (Sagebrush) as its two private sector fleet partners. Each company is a long-haul trucking company with significant activity in the DFW metropolitan area. Roehl was already a SmartWay Partner company at the time it was selected, and Sagebrush submitted an application to become a partner in conjunction with the study. A total of 41 trucks were selected to be outfitted with SmartWay upgrade kits. Additional discussion of the fleet characteristics of each company is included later in this report.

3 Demonstration Fleet and Technologies Used

The study called for identification of test trucks which would be outfitted with SmartWay upgrade kit technologies, as well as corresponding control trucks which would not have additional devices installed but would travel similar routes and report data in the same manner as the test trucks. Ultimately, fuel economy and emission impacts resulting from use of the SmartWay upgrade kits would be determined by evaluating differences in the performance data between the test trucks and control trucks.

The study intended for SmartWay upgrade kits installed on test vehicles to include one or more fuel-saving technology, one idle-reduction technology, and one emission control technology. The technologies which the partner fleets could select from are outlined in Table

1. Each partner fleet was given the opportunity to select a device of its choice within each category.

Table 1: Technologies Selected for Demonstration Project

Technology	**Selected by Partner Fleet**
Fuel-saving technologies	
Single-wide tires	Yes – Sagebrush
Automatic tire inflation	Yes – Sagebrush
Advanced trailer aerodynamics	
NO_x Reflash (for model years 1993-1998 only)	
Low viscosity lubricants	Yes – Roehl and Sagebrush
Mobile idle reduction technologies	
Bunk heater/Fuel Operated Heater (FOH)	
Auxiliary power unit (APU)	Yes – Roehl and Sagebrush
Emission control technologies	
Diesel oxidation catalyst (DOC)	Yes – Sagebrush
Crankcase filter	Yes – Roehl and Sagebrush
Diesel particulate filter	

3.1 Roehl Transport, Inc.

Roehl was awarded funds to outfit six trucks with SmartWay upgrade kit technologies, and another six units were identified as control trucks; both fleets are outlined in Table 2.

Table 2: Trucks Included in Study from Roehl Transport, Inc.

Truck Group	Study ID	Unit Number	Make	GVWR (pounds)	Engine Make	Model Year	Existing Technologies	SmartWay Technologies Installed
Test Trucks	T1	4373	Freightliner	80,000	Detroit	2006	FOH, Automatic Tire Inflation System, Fuel Efficiency Tires, and Aerodynamic Style Trailers	APU, Low Viscosity Lubricants, and Crankcase Filter
	T2	7354	Freightliner	80,000	Detroit	2006		
	T3	7527	Freightliner	80,000	Detroit	2006		
	T4	7881	Freightliner	80,000	Detroit	2006		
	T5	2202	Freightliner	80,000	Detroit	2006		
	T6	1262	Freightliner	80,000	Detroit	2006		
Control Trucks	C1	1600	Freightliner	80,000	Detroit	2006		Not Applicable
	C2	1711	Freightliner	80,000	Detroit	2006		
	C3	1612	International	80,000	Caterpillar C15 ACERT	2006		
	C4	1629	Freightliner	80,000	Detroit	2006		
	C5	7799	International	80,000	Cummins	2006		
	C6	7728	Freightliner	80,000	Detroit	2006		

All trucks contained engines of a similar model year, and 10 of the 12 trucks are of the same truck and engine make (Freightliner trucks with Detroit Diesel engines). Each truck was outfitted with an engine control module (ECM) which provided downloads of performance data. All Detroit Diesel engine ECMs were Motorola model DDC 3.01; the ECM of the Cummins engine was also manufactured by Motorola. In addition, all trucks had already been equipped with diesel FOHs, and the company specs automatic tire inflation systems, fuel-efficient tires, and aerodynamically shaped trailers as standard items for the majority of its fleet. These elements are pre-existing and consistent across all trucks. For each of its six test trucks, Roehl chose to install APUs, low viscosity lubricants, and crankcase filters. Thus, each test truck belonging to Roehl had the same configuration of SmartWay technologies. Technology installation occurred in the timeframe from October 2007 through February 2008.

It is important to note that through the course of the study period, Roehl began installing APUs across the majority of its fleet, including some of the control trucks. The implications of this action are explored later in this report.

Routes of travel for the test and control truck groups encompassed a wide geographic area. Figures 1 and 2 illustrate states in which the control truck and test truck groups traveled, respectively. These maps are based upon route data submitted as part of a monthly operational update by the company over four months, from June through September 2008. Notice that the routes traveled by the control fleet were more widely dispersed across the country than those traveled by the test fleet.

Figure 1: States Traveled by Roehl Control Fleet

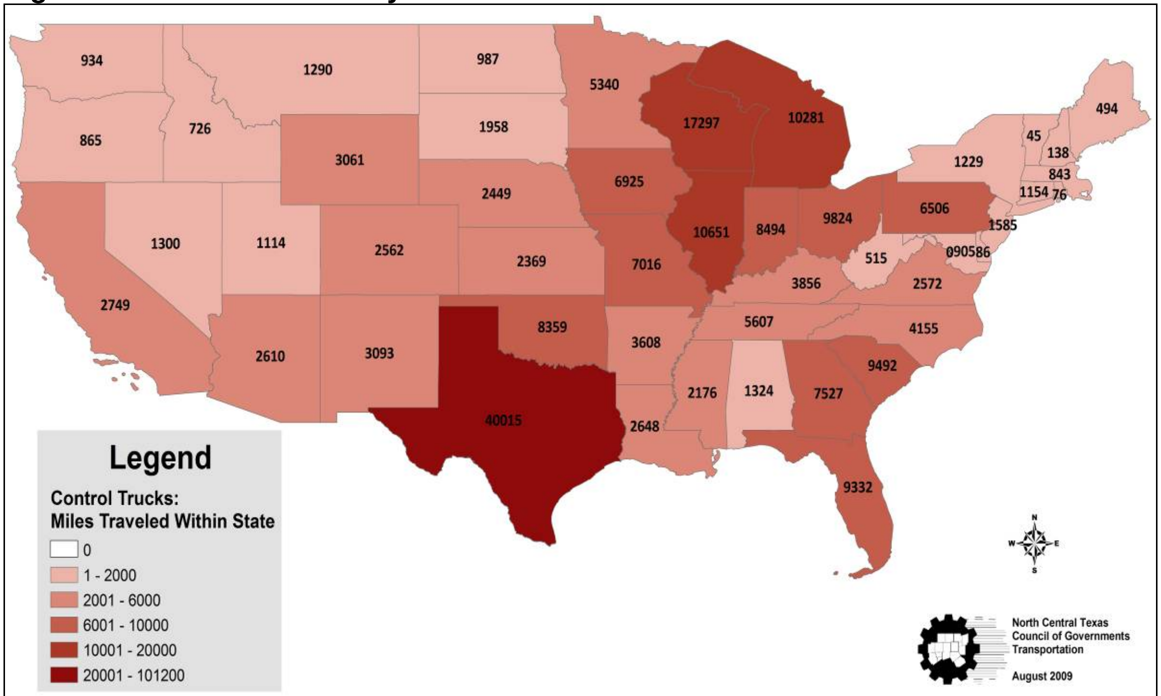
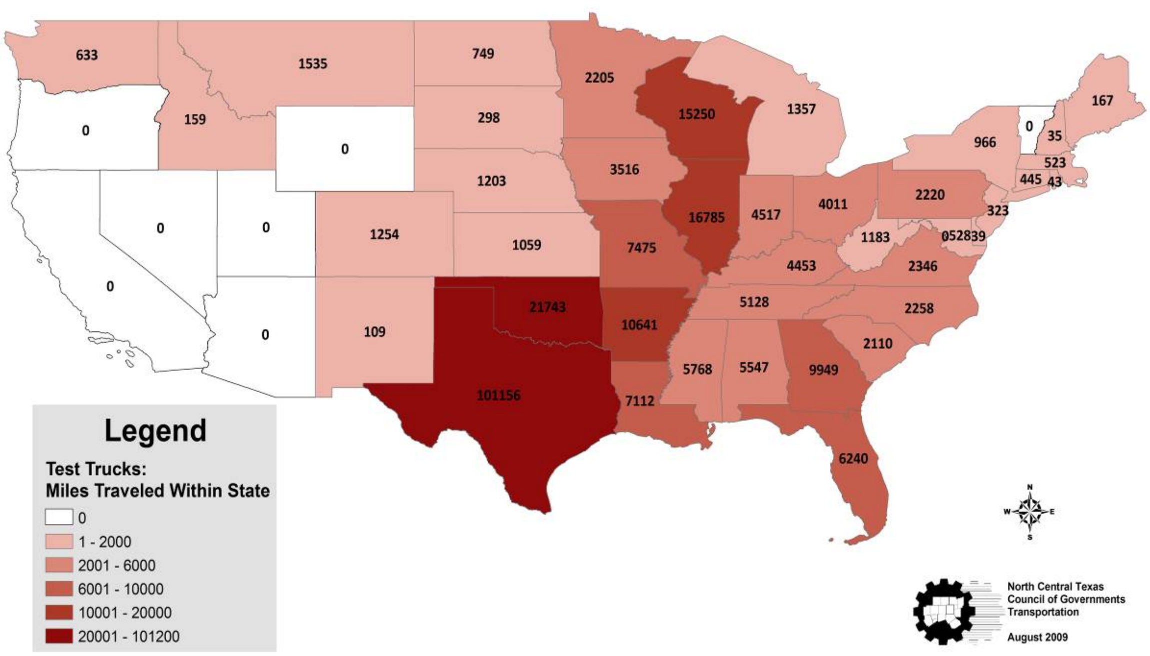


Figure 2: States Traveled by Roehl Test Fleet



3.2 Sagebrush Logistics, LLC

Through the competitive CFP, NCTCOG selected Sagebrush as the second industry partner and awarded funds to upgrade 35 trucks with SmartWay upgrade kits. The original study design would have allowed for analysis of these test trucks against the rest of the company's fleet as control trucks, as Sagebrush committed to collecting data on its entire fleet. This would have provided a fleet of more than 70 units to be used as control trucks. However, during the course of the study, the company separated into two divisions, thus splitting the fleet. As a result of this division, all the intended control trucks were separated into a separate fleet and were not accessible for the study. This left only the 35 test trucks for data collection and analysis. To provide for evaluation of the test period data against a control case, it was determined that Sagebrush would submit data for months preceding SmartWay technology installation to use as a control data set.

The Sagebrush study fleet and selected technologies are described in Table 3. All 35 trucks included in the study are manufactured by Freightliner and are of similar model year (2001-2003). Each is powered by a Detroit Diesel engine and is equipped with an ECM that is original to the truck; although the company did not have detailed information regarding the ECM, it believed all units to be identical. The technologies originally selected by the company for installation included an APU, single-wide tires (on some trucks), automatic tire inflation systems, and a DOC-crankcase filter combination for all 35 test trucks. Technology installation began during September 2007, but the company experienced difficulties with the automatic tire inflation systems and DOC-crankcase filter combinations soon after they were installed. These issues, which are described in further detail in the "Challenges" section, prompted changes in the technology configurations as the company chose to reconsider use of these devices.

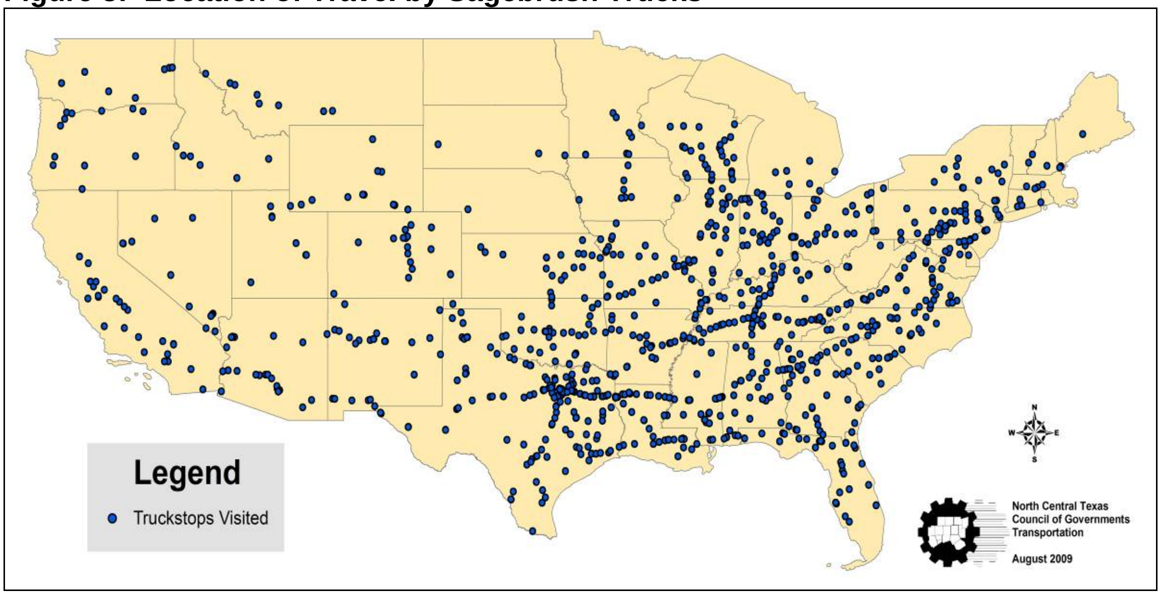
Table 3: Trucks Included in Study from Sagebrush Logistics, LLC

Truck Group	Study ID	Unit Number	Make	GVWR (pounds)	Engine Make	Model Year	Existing Technologies	SmartWay Technologies Installed
Group A	A1	2830	Freightliner	80,000	Detroit	2003	Aerodynamic Style Cabs with air dammed bumpers, fairings, and side wing extensions between cab and trailer	APU, Single-Wide Tires, DOC
	A2	2845	Freightliner	80,000	Detroit	2003		
	A3	2850	Freightliner	80,000	Detroit	2003		
	A4	2866	Freightliner	80,000	Detroit	2003		
	A5	6014	Freightliner	80,000	Detroit	2003		
	A6	6245	Freightliner	80,000	Detroit	2003		
	A7	6286	Freightliner	80,000	Detroit	2003		
	A8	6324	Freightliner	80,000	Detroit	2003		
	A9	7936	Freightliner	80,000	Detroit	2002		
Group B	B1	5337	Freightliner	80,000	Detroit	2001		APU, DOC
	B2	7259	Freightliner	80,000	Detroit	2001		
	B3	7698	Freightliner	80,000	Detroit	2002		
	B4	7877	Freightliner	80,000	Detroit	2002		
	B5	7892	Freightliner	80,000	Detroit	2002		
	B6	7898	Freightliner	80,000	Detroit	2002		
	B7	7948	Freightliner	80,000	Detroit	2002		
	B8	8076	Freightliner	80,000	Detroit	2002		
	B9	8178	Freightliner	80,000	Detroit	2002		
	B10	8254	Freightliner	80,000	Detroit	2002		
Group C	C1	1340	Freightliner	80,000	Detroit	2003		APU
	C2	1661	Freightliner	80,000	Detroit	2003		
	C3	1772	Freightliner	80,000	Detroit	2003		
	C4	1850	Freightliner	80,000	Detroit	2003		
	C5	2937	Freightliner	80,000	Detroit	2003		
	C6	7829	Freightliner	80,000	Detroit	2002		
	C7	7931	Freightliner	80,000	Detroit	2002		
	C8	8064	Freightliner	80,000	Detroit	2002		
	C9	8382	Freightliner	80,000	Detroit	2002		
	C10	8405	Freightliner	80,000	Detroit	2002		
	C11	8470	Freightliner	80,000	Detroit	2002		
	C12	9203	Freightliner	80,000	Detroit	2002		
	C13	9270	Freightliner	80,000	Detroit	2002		
	C14	9485	Freightliner	80,000	Detroit	2002		
	C15	9527	Freightliner	80,000	Detroit	2002		
Not Appli-cable	D	8050	Freightliner	80,000	Detroit	2002		APU, Single-Wide Tires

Sagebrush initially planned to replace the automatic tire inflation systems with low viscosity lubricants, and to use the DOCs as a stand-alone element. However, prior to completing installation of all SmartWay components, the company informed NCTCOG that it had ceased operation. Because it had been unable to complete all installations, some trucks had already been outfitted with a full upgrade kit; whereas, incomplete kits were in place on other trucks. The trucks therefore were classified into three groups. Complete upgrade kits, including an idle-reduction component, fuel-saving component, and emission-reduction component, were installed on one group of trucks, defined as Group A. Another group of trucks, Group B, contained both an idle-reduction component and an emission-reduction component, but no fuel-saving component. Finally, Group C contained an idle-reduction component only.

Typical routes of operation for these trucks included Interstates 10, 20, 30, 40, 35, and 55 from the DFW region to both coasts, and to the Mexican and Canadian borders. The routes traveled by trucks included in the study were estimated based upon the location of truck stops identified in fuel transactions; these locations are outlined in Figure 3.

Figure 3: Location of Travel by Sagebrush Trucks



4 Study Design

4.1 Quality Assurance Project Plan

A Quality Assurance Project Plan (QAPP) was submitted to EPA in November 2006, in keeping with the project contract. The QAPP focused on data quality control related to data collection and the evaluation of fuel savings and emissions reductions. The QAPP addressed critical steps necessary to ensure that the analysis resulting from the project met the objectives of the study, including the following:

- Quality Objectives and Criteria
- Documentation and Records
- Sampling Process
- Analytical Methods

- Instrument/Equipment Testing, Inspection, Maintenance, and Calibration
- Data Management
- Audits of Data Quality
- Corrective Actions
- Data Validation and Usability

The QAPP also outlined the statistical methodology used to evaluate fuel economy in miles per gallon (MPG) and emissions impacts resulting from use of the SmartWay upgrade kits. Per the QAPP, the following phases of analysis were to be used to estimate differences between test trucks and control trucks:

- Difference between composite fuel economy for fleet-specific test trucks versus their identified control truck counterparts,
- Difference between composite fuel economy for individual truck bins versus the entire control truck population, and
- Difference between composite fuel economy for the entire test truck population versus the entire control truck population.

The QAPP also outlined the statistical methodology to be used during data analysis. This methodology was held constant across all phases of analysis and is detailed in section 4.3.

4.2 Data Collection

Each of the private sector trucking fleet partners were responsible for collecting and reporting data on a monthly basis for all trucks included in the study (both test trucks and control trucks). Both companies utilized software systems that allowed for downloads of performance data from the ECM and also provided transaction logs which detailed each fuel purchase.

The original study design called for monthly reports including the following elements:

- ECM download containing performance data,
    - Average Speed
    - Miles Traveled
    - Fuel Economy
    - Idle Time
- Truck VIN,
- Date,
- Time,
- Name of Data Collector,
- Overall work status,
- Supporting documentation regarding fuel economy data (fuel transaction reports, driver reports, fuel receipts),
- Any change in operational characteristics,
- Any identified problems arising during data collection and corrective actions taken,
- Any testing, inspection, maintenance, and calibration of ECMs,
- Any other difficulties that may affect the project schedule and proposed solutions,
- Any irregularities in operation of any test or control truck, and
- Driver feedback regarding the SmartWay upgrade kit technologies.

Each month, NCTCOG staff performed an Audit of Data Quality (ADQ) to review the data received for completeness and validity. Each audit also included cursory evaluation of outliers for each month to determine whether any corrective actions needed to be taken or if a certain measurement would likely need to be discarded during final analysis.

4.3 Data Analysis

The analytical methodology proposed for this study is identical for each phase of estimation. The steps of this methodology are summarized below:

Calculate Composite Fuel Economy
The sample mean for the population of interest was calculated to derive the composite fuel economy for that population. The standard deviation of the sample mean, along with confidence interval, was calculated to determine the dispersion of the data set. Outliers were identified using a tool called the fourth spread and excluded from the analysis to avoid skewing of results.

Determine Population Distribution
The population distribution was tested for normality to indicate use of parametric or nonparametric statistical tools. A frequency histogram of MPG data was developed as a visual method for identifying the underlying distribution.

Compare Populations (Parametric Methodology)
All data sets exhibited a normal distribution; thus, the statistical tool used to compare the test truck population against the control truck population was the two-sample t-test, assuming unequal variances. When determined to be statistically significant, the estimated difference between the control and test case is reported as overall percentage change.

Over the course of the study, significant differences developed in data collection and, consequently, data analysis between the two subgrantee fleets. Because of the different characteristics, analysis phases were confined to Roehl trucks only or Sagebrush trucks only; analysis of both companies' trucks as one group was not considered to be valuable or appropriate. Discussion of the analysis phases, and associated conclusions, are therefore divided by partner fleet to avoid confusion.

5 Roehl Transport, Inc.

5.1 Data Collection

The initial study design called for as many as 260 data points per truck, based upon an assumption that MPG data would be measured on a daily basis. However, it was determined that monthly downloads of ECM data was appropriate to fit the needs of the study and also company operations. The use of ECM data provides for an automated process with minimal human error and a high degree of reliability. Roehl conducted an ECM download at the end of each month and also each time the truck was operated by a new driver. Thus, there is great variability in the amount of time reflected in one ECM download. In some cases, a full month is reported by a single download. In other cases, four different downloads make up one month worth of reporting, as four different drivers operated that particular truck during that month. By collecting a download each time a driver changed, the frequency of driver changes was easily identified. Roehl also submitted fuel transaction logs for the duration of the study period which provided a data point for each fuel purchase throughout the study period. This information served as a point of validation during data analysis. The scope of the data set received from Roehl over the 12-month study period is outlined in Table 4.

Table 4: Description of Data Sets Collected by Truck, Roehl

Truck Group	Truck Unit Number	ECM Downloads	Months Of Fuel Data	Individual Fuel Transactions
Test 1	4373	12	7	90
Control 1	1600	16	7	97
Test 2	7354	15	7	76
Control 2	1711	14	7	83
Test 3	7527	15	7	67
Control 3	1612	29	7	68
Test 4	7881	13	7	73
Control 4	1629	15	7	95
Test 5	2202	16	7	102
Control 5	7799	15	7	83
Test 6	1262	12	7	92
Control 6	7728	12	7	90

Of the 12 trucks, ten trucks reported data in an identical format using the SensorTRACS™ system. However, the ECM download from Test Truck 6 and Control Truck 6 was gathered using the TruckPC™ system from Driver Tech and therefore reported slightly different parameters. For the purposes of this study, the key differences were that the ECM downloads from these two trucks did not include speed, driving MPG, or extended idle percent estimates. Thus, analysis of these measurements included data from only the ten trucks with identical reports.

5.2 Data Analysis

Recall from discussion of the QAPP that three phases of analysis had been proposed. These phases were streamlined as all trucks contained identical configurations of SmartWay technologies. Thus, for the Roehl truck group, only one analysis phase was conducted:

- Difference between composite fuel economy and emissions for all Roehl test trucks versus all Roehl control trucks.

Analysis of data received was based predominantly upon ECM download data, with fuel receipts serving as corroborating data. For months in which more than one ECM download was received for a single truck, staff calculated one data point to be used during data analysis. This was estimated by quantifying gallons consumed per driver (based upon MPG and mileage reported per driver), then summing all gallons consumed and distance travelled for all drivers in that month to calculate composite monthly MPG. After establishing one data point per month, the data set yielded 72 total observations for both the control truck and test truck data sets. Recall that not all parameters are reported for all twelve trucks; in addition, one test truck failed to report for one month. Critical parameters evaluated included the following data points:

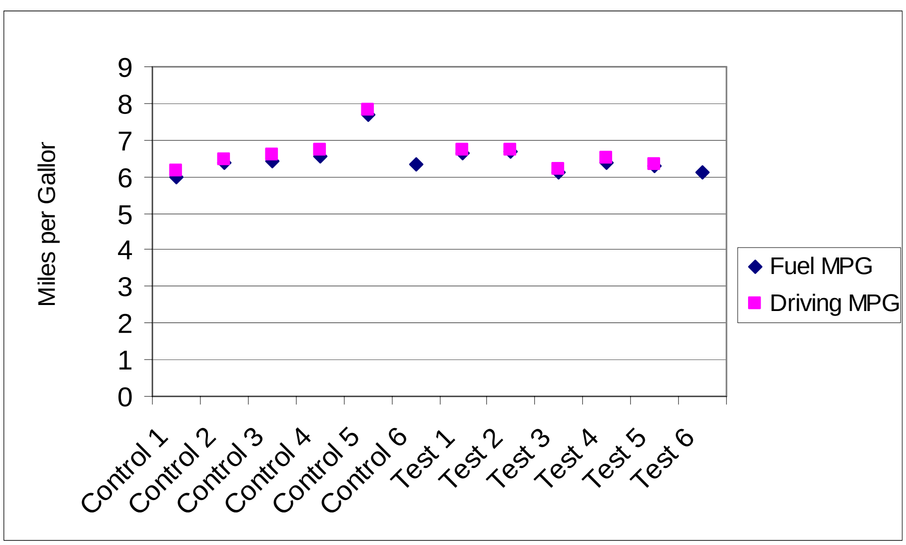
- Overall Fuel Economy (Fuel MPG)
- Driving Fuel Economy (Driving MPG)
- Speed (Average miles per hour, MPH)

The Driving MPG excludes fuel consumed while the engine is at idle from its calculation, which is consistent with it reflecting a higher fuel economy. Thus the Driving MPG is a more accurate representation of MPG achieved during normal over-the-road operation. The raw average value for each of these parameters over the 12-month study period is outlined in Table 5 and presented graphically in Figures 4-5.

Table 5: Key Performance Measures, Averaged Over Study Period: Roehl

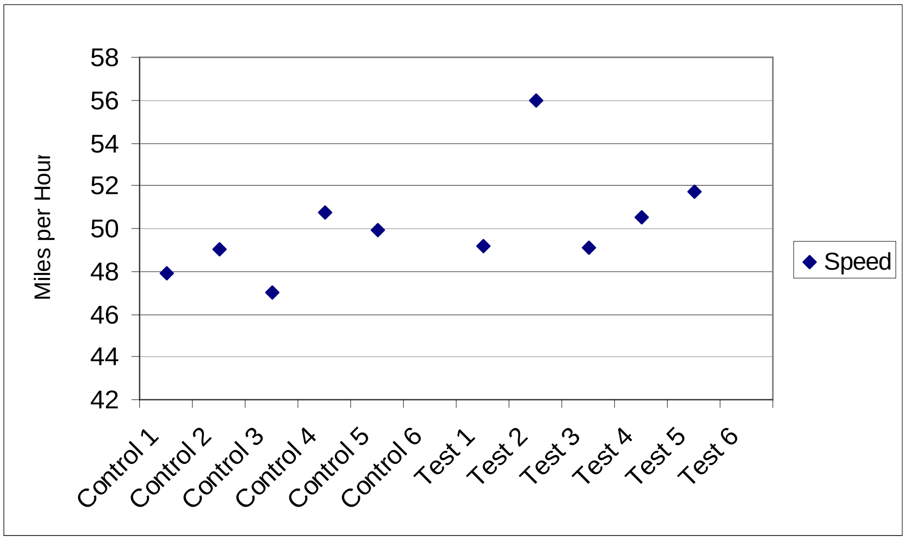
Truck	Average Speed (MPH)	Fuel MPG	Driving MPG	Extended Idle Percent
T1	49.17	6.66	6.71	0.00%
C1	47.89	5.97	6.14	1.26%
T2	56.00	6.70	6.75	0.00%
C2	49.00	6.37	6.44	5.49%
T3	49.11	6.12	6.19	1.04%
C3	47.00	6.42	6.60	5.86%
T4	50.55	6.36	6.51	5.53%
C4	50.78	6.57	6.72	3.97%
T5	51.70	6.29	6.34	0.41%
C5	49.89	7.70	7.81	2.39%
T6	Not Available	6.10	Not Available	Not Available
C6	Not Available	6.36	Not Available	Not Available
All Test Trucks	51.25	6.37	6.50	1.63%
All Control Trucks	49.10	6.56	6.74	3.81%

Figure 4: 12-Month Average Fuel Economy, By Truck



Note that in all cases, the Driving MPG is slightly higher than the Fuel MPG. Furthermore, the raw averages seem to indicate that the fuel economy of the control truck group is actually better than the fuel economy of the test truck group, which is counter to the intent of utilizing SmartWay technologies. However, the raw averages also show that the overall speed of the test truck group is higher than that of the control trucks, which may negatively impact the fuel economy of the test truck group due to increased resistance and drag. The more detailed discussion and analysis of each parameter that follows evaluates whether the apparent differences in measurement are statistically significant.

Figure 5: 12-Month Average Speed, By Truck



5.2.1 Fuel Economy

The first step in analyzing the data set was to identify outliers to be excluded from data analysis. Note in Figure 4 that truck C5 appears to have averaged significantly higher fuel economy that the remaining group of trucks. NCTCOG first identified outliers based upon three standard deviations. However, doing so only resulted in the exclusion of one observation from truck C5, despite the fact that multiple observations appeared to trend high. This particular truck had been identified as a likely outlier throughout data collection during monthly ADQs. Because of the potential for the observations from this truck to skew the overall data set, including both the calculated mean and standard deviation, it was determined that standard deviation is not the best method to identify outliers for this data. Rather, outliers were identified by determining the fourth spread (f_s) of the data set, which is based upon the center of a data set and is therefore less subject to skewing due to more extreme measurements.[1] Using the fourth spread, measurements that were either a "mild outlier" ($1.5 * f_s$) or an "extreme outlier" ($3 * f_s$) were identified as shown in Table 6.

Upon further analysis of the mild outliers in the control truck group, it was discovered that the four data points in the Fuel MPG data set and five of the seven measurements in the Driving MPG data set were associated with truck C5, which is consistent with visual analysis of the data in Figure 3. The remaining outliers were associated with one or two observations from various different trucks. Furthermore, staff had previously identified this truck as a potential outlier through monthly ADQs. Conversation with Roehl staff regarding these outliers

[1] Devore, Jay L. *Probability and Statistics For the Engineering and Sciences*. 5th Ed. Duxbury Thomson Learning. 2000.

revealed that the company has noticed a larger margin of error with the ECM of the Cummins engine in this truck as compared to those on the Detroit Diesel engines.

Table 6: Description of ECM Data Set – Fuel Economy

Parameter	Truck Group	Total Observations	Extreme Outliers	Mild Outliers	Observations Excluding Extreme Outliers	Observations Excluding All Outliers
Fuel MPG	Control Trucks	72	0	4	72	68
	Test Trucks	71	1	3	70	67
Driving MPG	Control Trucks	60	0	7	60	53
	Test Trucks	59	0	1	59	58

After identifying outliers, frequency histograms determined that the population displayed normal distribution, both for Fuel MPG and Driving MPG. Thus, a two-sample t-test was conducted to compare the fuel economy measurements from the control truck group to those of the test truck group. Analysis was conducted for both Fuel MPG and Driving MPG for two scenarios each: one excluding only the single extreme outlier, and another excluding all outliers (both extreme and mild), thus better insulating results from potential skewing of data which could result from the inclusion of data from truck C5. Table 7 outlines the t-test results.

Table 7: Results of t-test Comparison – Fuel Economy

t-test Analysis	Data Set	Control Truck Fleet MPG	Test Truck Fleet MPG	Statistically Significant Difference in Fuel Economy?	% Change
Excluding Only Extreme Outliers	Fuel MPG	6.56	6.37	Yes	-3.0%
	Driving MPG	6.74	6.49	Yes	-3.7%
Excluding All Outliers	Fuel MPG	6.47	6.42	No	--
	Driving MPG	6.65	6.51	No	--

As outlined in Table 7, when only extreme outliers are excluded, the fuel economy of the control truck group appears to be higher than the fuel economy of the test truck group. However, when all outliers are excluded, there is no statistically significant difference in the fuel economy of the truck groups. This suggests that the measurements associated with truck C5 do greatly impact the results of the data analysis.

Fuel transaction logs were used to corroborate the data supplied by the ECM. Staff plotted Fuel MPG as reported by the ECM against a “calculated” fuel economy which was estimated from total gallons purchased and total mileage driven in a given month, based upon odometer readings associated with each fuel transaction. In general, both the fuel log and ECM data sets revealed the same trends in terms of truck fuel economy. However, Roehl had indicated that, in their experience, the ECM tends to over-report fuel economy by approximately one to one and a half miles per gallon. The comparison of ECM versus calculated fuel economy supported this claim, as the Fuel MPG reported from the ECM was consistently higher than that calculated based upon fuel logs. The discrepancy in the two data points ranged from 0.01 to 2.81 miles per gallon. The largest difference was consistently found with data from truck C5, as the fuel transactions suggested an average fuel economy much more in keeping with the fuel economy values of the other control trucks.

Roehl indicated that the company considers fuel economy as calculated from fuel transactions to be more reliable than that reported from the ECM because of the inflated value reported by the ECM. NCTCOG found that the standard deviation of fuel economy derived from this data was actually smaller than that of the ECM data. Therefore, staff conducted the same statistical analysis of MPG estimated from the fuel transactions to determine if the different data set yielded the same result. In this evaluation, only one fuel economy data point from truck T5 was found to be a mild outlier. Consistent with analysis of the ECM data, t-test analyses of this data set did not reveal any statistically significant difference between fuel economies of the test fleet versus control fleet.

5.2.2 Speed

Outliers among speed measurements were also determined using the fourth spread methodology; results are described in Table 8.

Table 8: Description of ECM Data – Speed

Truck Group	Total Observations	Extreme Outliers	Mild Outliers	Observations Excluding Extreme Outliers	Observations Excluding Extreme and Mild Outliers
Control Trucks	42	0	0	42	42
Test Trucks	52	0	15	52	37

As the data population was determined to also have a normal distribution, a two-sample t-test was conducted to compare the difference between speeds of the two truck groups. Table 9 illustrates the results. Again, analysis was conducted for the entire data set and for the data set excluding all outliers.

Table 9: Results of t-test Comparison – Speed

t-test Analysis	Control Truck Fleet Average Speed (MPH)	Test Truck Fleet Average Speed (MPH)	Statistically Significant Difference in Speed?	% Change
Including All Observations	49.1	51.3	Yes	4.4%
Excluding All Outliers	49.1	50.7	Yes	3.2%

Unlike the results of fuel economy analysis, the difference in speed between the truck groups is statistically significant regardless of the inclusion of outliers. Because higher speeds negatively impact fuel economy, this is an important point to consider when evaluating the fuel economy results.

5.3 Conclusions and Discussion

5.3.1 Fuel Economy Impacts

Although the data does not suggest an improvement in fuel economy among the test trucks, it should not be interpreted that there are no potential benefits which may be associated with SmartWay technologies. Analysis of fuel economy for Roehl is complicated by the fact that the test trucks were traveling at a higher speed than the control trucks. The Department of

Energy suggests that speed is the largest influence on fuel economy among Class 8 trucks.[2] Therefore, it is possible that this difference in speed negated improvements in fuel economy which could have been attributable to the use of SmartWay upgrade kits. The lack of statistically significant changes in fuel economy between the truck groups could be interpreted to suggest that the upgrade kits did provide some benefit, as the increased speed among the test trucks should have resulted in more significant decreases in fuel economy.

Through discussion with Roehl, three explanations for this higher speed have been speculated. Per the study design, the company selected trucks that were assigned to dedicated routes as test trucks, which resulted in several characteristics that set this group apart from the rest of the company fleet. First, these drivers were on a different pay structure than many of their counterparts and were paid by the hour rather than by the mile. Secondly, these trucks were not based at the company headquarters, which made it more difficult for them to be brought in for maintenance or recalibration. During the study period, the company reset the speed parameters of the ECMs, reducing the maximum allowable speed from 65 to 63 MPH, and reducing cruise speed to 61 MPH. As the test trucks were domiciled away from headquarters, it is possible that the control trucks were recalibrated earlier and thus began traveling slower due to the new constraints. Finally, because test truck drivers traveled dedicated routes, it is possible that they had a greater familiarity and degree of comfort with the roadways and terrain along these routes which could have led to a higher speed than their control truck counterparts who drove more variable paths.

In addition, discussion with the company indicated that Roehl initiated several performance-based initiatives and driver awareness programs, which may have also influenced fuel economy by encouraging more efficient driving habits and other behavioral changes. These operational differences could make it difficult to draw conclusions based upon the analysis conducted. Along with the difference in speed between the two fleets, it underscores the need for consistent driver behavior in order to conduct analyses such as those in this report.

5.3.2 Extended Idle Time

Because the Driving MPG measurement excludes fuel consumed during idle time, analysis of this parameter is insulated from the impacts of idling. Therefore, statistical analysis of idle time was not necessary to evaluate changes in MPG. However, a brief discussion of idle time between truck groups is appropriate to determine whether the presence of an APU resulted in real-world decreases in extended idle time.

Recall that APUs were installed on all six text trucks at the beginning of the study, and during the 12-month data collection period Roehl also installed APUs on several of its control trucks. Each truck included in the study had been equipped with an FOH to help reduce idling during colder times of the year prior to installation of APUs. The overall incidence of extended idling time among trucks included in the study is outlined in Table 10.

Table 10: Incidence of Extended Idling

Truck Group	Total Observations	Observations with Idle Time >0	Observations with Idle Time > 3%	Range of Idle Time
Control Trucks	60	26	14	0-32%
Test Trucks	59	9	4	0-19%

[2] Department of Energy. Alternative Fuels and Advanced Vehicles Data Center. www.afdc.energy.gov/afdc/vehicles/fuel_economy_heavy.html.

Note that both the frequency and the length of extended idle time is greater among the control trucks, which supports the assumption that the installation of an APU greatly reduces extended idling. Indeed, all four of the instances in which a test truck reported more than three percent total idle time were associated with documented incidents of APU malfunction or a need for driver training on its use.

Monthly reports on the overall status of the project included an opportunity to include driver feedback. Driver comments regarding APUs were generally positive, though in the early months of the study it appears that several devices required repair and/or maintenance before they would run smoothly. Anecdotal evidence from the company indicated that fleetwide idle time has greatly been reduced since APU installation was conducted across the fleet.

5.4 Emissions Reductions and Fuel Savings Achieved

Since there is no net change in fuel economy between the test trucks and control trucks, emissions reductions cannot be quantified based upon this parameter. However, emissions benefits were estimated based upon the difference in overall extended idle time between the test truck group and control truck group, using the following equations:

NO_x or Particulate Matter (PM) Emissions Reduced = (Difference in Total Hours Extended Idling) x (Idling Emission Factor)

CO_2 Emissions Reduced = (Difference in Total Hours Extended Idling) x (0.8 Gallons Diesel Consumed per Hour Idling[3]) x (22.2 Pounds CO_2 per Gallon Diesel[4])

Note that because APUs were also installed on control trucks, the difference in idle time between the truck fleets is diluted. This leads to an underestimating of emissions reductions achieved over the 12-month study period. Emissions reductions estimated using this data, which are shown in Table 11, should therefore be considered extremely conservative estimates of the emission reduction potential of APU utilization.

Table 11: Emissions Reductions Achieved

Control Fleet Extended Idling Hours (12-month cumulative total)	Test Fleet Extended Idling Hours (12-month cumulative total)	Idling Emission Factor (grams/hour)[5]			Emissions Reduced (pounds, 12-month cumulative total)		
		NO_x	PM	CO_2	NO_x	PM	CO_2
511.88	168.90	135	3.68	NA	102.08	2.78	6,091.38

Reduction in idle time not only results in emissions reductions, but also in lower fuel costs. Using the same estimates above, the reduction in extending idling hours led to a savings of approximately 274.4 gallons of diesel fuel. Assuming an average cost of $3.76 per gallon of diesel, this equates to $1,031.68 saved over the 12-month study period through the use of

[3] Environmental Protection Agency. *A Glance at Clean Freight Strategies: Idle Reduction*. U.S. EPA. www.epa.gov/smartway/transport/documents/carrier-strategy-docs/apu.pdf.
[4] Environmental Protection Agency Office of Transportation and Air Quality. *Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel.* February 2005. www.epa.gov/otaq/climate/420f05001.pdf.
[5] Environmental Protection Agency Office of Transportation and Air Quality. *Guidance for Quantifying and Using Long Duration Truck Idling Emission Reductions in State Implementation Plans and Transportation Conformity*. January 2004. www.epa.gov/smartway/documents/420b04001.pdf.

APUs on the six test trucks, or approximately $171.95 per truck. This price is based upon the annual cost of on-highway diesel in 2008 for the Midwest region, as reported by the Energy Information Administration.[6] Although these savings are significantly lower than those often cited in relation to the use of APUs, discussion with the company indicated that Roehl has experienced a significant return on investment that has prompted additional APU purchases across the fleet. The low numbers suggested by the data result from several factors. Roehl employed diesel FOHs on both the control and test fleet, which provides an estimated fuel savings of up to three-fourths of a gallon per hour as compared to operating the main engine. Therefore, the reductions reported here reflect the incremental savings that are attributable to use of an APU in addition to the reductions already attained by the FOH. Furthermore, the installation of APUs on the control fleet during the course of the study leads to an underestimating of fuel savings as the distinction between test and control trucks with regard to idle reduction was eliminated. This precludes a clear calculation of return on investment using this data.. Since Roehl had already been attentive to the cost of unnecessary idling and had relatively low extended idle times fleet-wide at the beginning of the study, these numbers may be used for estimation purposes by companies considering investments in APUs in place of FOHs. As the company continues to invest in APUs for its fleet, additional savings will build over time.

In addition to the emission reductions outlined as a result of reduced idle time, further reductions in PM emissions were achieved through use of crankcase filters on the test fleet.

6 Sagebrush Logistics, LLC

6.1 Data Collection

Sagebrush had originally agreed to submit ECM downloads and fuel transaction data as outlined in the QAPP. However, because of difficulties experienced during the technology installation phase of the project, Sagebrush had not begun the formal "test period" of data collection prior to ceasing operations in September 2008. From July to September 2008, Sagebrush submitted data including a single ECM download for each truck in its fleet as of that time. NCTCOG analyzed the ECM data set received and determined that it was insufficient to conduct the intended analysis. This was largely due to the fact that only one download was submitted per truck, and in many cases included performance data from several years. Therefore, performance measures of interest reflected operational conditions both with and without SmartWay technology installation. It was therefore not possible to separate measurements of fuel economy under control conditions from that under test conditions. NCTCOG attempted to construct as many control and test scenarios as possible based upon the data available, but the resulting population of ECM data points was determined to be too small to provide for valid statistical analysis. Due to these shortfalls in the ECM data set, analysis was conducted primarily on information contained in the fuel transaction logs. ECM reports were used as corroborating data only.

Sagebrush submitted fuel receipts compiled through the Comdata® reporting system which included each fuel transaction recorded for every truck in its fleet for all of calendar year 2007 and for calendar year 2008 through the end of July. Each fuel receipt included a mileage measurement as well as quantity of fuel purchased. The number of gallons purchased for each truck under study was summed for each month. Then, by identifying the first and last

[6] Energy Information Administration, http://tonto.eia.doe.gov/dnav/pet/pet_pri_gnd_a_epd2d_pte_cpgal_a.htm.

fuel transaction for a given month, NCTCOG estimated miles traveled and calculated a composite fuel economy data point.

It should be noted that not every truck under evaluation had fuel transaction data for each month. Notably, Truck B10 was involved in a wreck in April 2008, leaving it with fewer data points. Also, several trucks in Group C did not appear in the fuel transaction data set until several months into 2007.

6.2 Data Analysis

Recall that during the study period, business conditions led Sagebrush to divide its fleet; the company retained ownership of all test units, but was left with no trucks to use as a control fleet. To create the opportunity for test versus control truck comparison, the monthly fuel transactions were cross-referenced with the month(s) of SmartWay technology installations to determine which months of fuel data represented "control" conditions (before installation) and which reflect "test" conditions (after technology installation). Differences in control truck versus test truck fuel economy were therefore evaluated by comparing the data set for each truck group before and after installation. Truck C5 was not included in this analysis, however, as the month of APU installation was not identified and NCTCOG could therefore not differentiate between control and test conditions. Additionally, Truck D was not included in the analysis as there were no cohort trucks with the same configuration, leaving too small a sample size for this arrangement of SmartWay technologies to be evaluated.

Analysis phases among Sagebrush trucks are more detailed than those for Roehl, as different configurations of technologies were installed. The analysis phases conducted for this fleet of trucks were consistent with those outlined in the QAPP:

- Difference between composite fuel economy for Sagebrush truck Group A under test conditions versus control conditions,
- Difference between composite fuel economy for Sagebrush truck Group B under test conditions versus control conditions,
- Difference between composite fuel economy for Sagebrush truck Group C under test conditions versus control conditions,
- Difference between composite fuel economy for Sagebrush truck Group A under test conditions versus control conditions for the entire group of trucks,
- Difference between composite fuel economy for Sagebrush truck Group B under test conditions versus control conditions for the entire group of trucks,
- Difference between composite fuel economy for Sagebrush truck Group C under test conditions versus control conditions for the entire group of trucks, and
- Difference between composite fuel economy for all Sagebrush trucks under test conditions versus control conditions.

During estimation of monthly composite fuel economy for each truck, NCTCOG found several inconsistencies in the mileage measurement, such as instances where mileage decreased from one purchase to the next or was missing completely. Discussion with Sagebrush revealed that the mileage was input by each driver, and many drivers likely made mistakes or neglected to enter this data. To help minimize the impact of these errors when estimating monthly fuel economy, NCTCOG discarded fuel transactions which were noticeably inconsistent with other transactions entered during that same month (i.e. the first receipt indicated 65,000 miles, and all other entries that month reported mileage in the 45,000-mile range) in order to keep as many data points as possible. However, in some cases, the variability in mileage entered throughout the month was so great that NCTCOG could not identify the individual entries that were obvious errors; thus, some monthly fuel economy calculations resulted in unrealistic estimates (i.e. negative numbers or MPG in excess of 100 miles per gallon) that necessitated the discarding of that entire month's data.

To proceed with data analysis, outliers had to be clearly identified. Because of the potential skewing from "bad" fuel economy data points, identification of outliers based upon standard deviation was not preferred. To minimize distortion of the data set, outliers were identified using the fourth spread methodology previously discussed. Fuel economy data was separated into four subsets: Group A, Group B, Group C, and all truck data, and within each subset was grouped as "control" or "test" data based upon date. The data set is outlined in Table 12.

Table 12: Description of Sagebrush Data Set

Truck Group	Control Condition Data			Test Condition Data		
	Total Observations	Mild Outliers	Extreme Outliers	Total Observations	Mild Outliers	Extreme Outliers
Group A	62	2	9	93	2	11
Group B	62	6	7	91	4	6
Group C	50	0	4	149	3	4
All Trucks	174	7	15	333	8	22

NCTCOG conducted t-test statistical analyses for each phase described at the beginning of this section. Each phase was evaluated under two scenarios: excluding only extreme outliers, and excluding all outliers. Table 13 presents the results of these analyses.

Table 13: t-test Analysis Results

Analysis Phase	Scenario	Control Condition Fuel Economy	Test Condition Fuel Economy	Statistically Significant Difference?	% Change
Group A Test vs. Control Data	Excluding Only Extreme Outliers	5.20	5.81	Yes	11.7%
	Excluding All Outliers	5.19	5.87	Yes	13.0%
Group B Test vs. Control Data	Excluding Only Extreme Outliers	5.46	5.64	Yes	3.4%
	Excluding All Outliers	5.55	5.65	No	--
Group C Test vs. Control Data	Excluding Only Extreme Outliers	5.04	5.52	Yes	9.5%
	Excluding All Outliers	5.04	5.51	Yes	9.3%
Group A Test vs. All Truck Control Data	Excluding Only Extreme Outliers	5.23	5.81	Yes	11.1%
	Excluding All Outliers	5.25	5.87	Yes	11.8%
Group B Test vs. All Truck Control Data	Excluding Only Extreme Outliers	5.23	5.64	Yes	7.9%
	Excluding All Outliers	5.25	5.65	Yes	7.7%
Group C Test vs. All Truck Control Data	Excluding Only Extreme Outliers	5.23	5.52	Yes	5.5%
	Excluding All Outliers	5.25	5.51	Yes	5.0%
All Truck Group Test vs. Control Data	Excluding Only Extreme Outliers	5.23	5.64	Yes	7.8%
	Excluding All Outliers	5.25	5.64	Yes	7.5%

6.3 Conclusions and Discussion

The data from Sagebrush consistently shows an increase in fuel economy under test conditions, after installation of the various SmartWay technologies. The largest increases in fuel economy are shown among Truck Group A, which is the group in which a full upgrade kit was installed (APU, single-wide tires, and DOC). This suggests that the presence of a variety of SmartWay technologies does indeed provide for an increased fuel efficiency benefit as opposed to using individual devices. When evaluating the results of an individual truck group between its control and test data, the second-largest increase in overall fuel economy occurred among Truck Group C, on which only APUs were installed. This suggests that the reduction in idle time is one of the most significant influences on fuel consumption. Reasons for the minimal increase in fuel economy between the control and test condition data Group B are unclear, though it should be noted that the Group B control condition MPG was higher than that of any other truck group. The technology installation on Group B includes a DOC, which is often cited as having a slight fuel penalty. However, the data does not clearly indicate that the DOC negatively impacted fuel economy, as Group B does maintain an improvement in fuel economy as compared to the control condition data from the entire truck fleet, and the inclusion of a DOC on Group A did not appear to impact the fuel economy improvement for that group. Indeed, when each individual truck group is compared to the control condition data from the entire fleet, the improvement in fuel economy increases proportionally to the number of SmartWay technologies installed.

Although the data indicate an increase in fuel economy, operational factors which are unrelated to the installation of SmartWay technologies may influence these changes. These factors are not visible in the data available. Notably, performance metrics such as speed and idle time, which help clearly identify changes in operating conditions or driver behavior, are unavailable in the fuel transaction data set. It is possible that Sagebrush, like Roehl, began to institute driver awareness programs and incentives for greater efficiency. Discussions with company management through the course of the study indicated an interest in initiating such efforts, but it is unknown whether these were implemented prior to the company closing. Any such programs could have impacted overall fuel economy, and results would likely have become more apparent in the latter months of the test condition time period. Additionally, driver turnover among the Sagebrush fleet seemed to be much lower than in the Roehl fleet, both within a single month and across months, so changes in behavior of an individual driver likely would be reflected in that particular truck's performance parameters. However, such influences should have been present across all trucks in the study, and the different rates of increase among different truck groups suggest impacts that may be related directly to technology improvements.

To attempt to evaluate operational changes, NCTCOG reviewed all ECM downloads received to identify any trends in idle time, fuel economy, or speed. Each download reported performance measures for the full life of the truck, and also isolated the last three months of operation. These last three months therefore may be considered as reflective of test conditions, with the report covering the full life of the truck an approximate representation of control conditions. Among the trucks included in Group C, ECM downloads are available to evaluate test and control conditions for seven units. In all seven trucks, the percent of idle time noticeably decreased in the final months of the report as compared to the life report (i.e. idle time for Truck C7 decreased from approximately 50 percent to 21-24 percent). If this change in idle time positively impacted fuel economy, then the estimated fuel economy for these three final months would be expected to trend higher than that reported over the life of the truck. However, this did not hold true; no trend in fuel economy was visible among these trucks. Review of the ECM data from Truck Groups A and B were similar, as the data exhibited consistent decreases in idle time but no corresponding trend in fuel economy. No noticeable change was visible regarding truck speed. Although this data set is too small to draw clear conclusions, it suggests that the overall fuel economy improvement may be heavily attributable to technology as operational factors were highly variable.

6.4 Emissions Reductions and Fuel Savings Achieved

As statistically significant increases in fuel economy resulted among the Sagebrush trucks after SmartWay technology installation, resulting emissions reductions achieved were quantified using the equations below for each truck group, under both control and test conditions:

NO_x or PM Emissions (grams/mile) = (certified engine standard in grams/bhp-hr) * (inverse of fuel economy in gallons/mile) * (energy consumption factor in bhp-hr/gallon)

CO_2 Emissions (grams/mile) = (22.2 pounds CO_2/gallon diesel) * (inverse of fuel economy in gallons/mile) * (453.6 grams/pound)

Inputs for these equations were based upon model year 2002 engines. Thus, it was assumed that the engines of all were certified to emissions standards of 4.0 g/bhp-hr NO_x and 0.1 g/bhp-hr PM and had an energy consumption factor of 19.8 bhp-hr/gallon[7]. Reductions in the emissions rate for each truck group are quantified in Table 14. Note that as the change in fuel economy impacts all pollutants the same, the reduction in emissions rate is identical for all pollutants. Although actual emissions rates may not be linear to fuel economy, this is the best estimate available using the equations above, without measuring actual exhaust emissions through portable emissions monitoring equipment.

Table 14 : Range of Emissions Reductions Achieved, Based Upon Fuel Economy

Analysis Phase	Scenario	Control Emission Rate, grams/mile			Test Emission Rate, grams/mile			% Reduction in Emission Rate		
		NOx	PM	CO_2	NOx	PM	CO_2	NOx	PM	CO_2
Group A Test vs. Control Data	Excluding Only Extreme Outliers	15.23	0.38	1936	13.63	0.34	1733	10.48%	10.48%	10.48%
	Excluding All Outliers	15.25	0.38	1940	13.50	0.34	1716	11.51%	11.51%	11.51%
Group B Test vs. Control Data	Excluding Only Extreme Outliers	14.51	0.36	1845	14.03	0.35	1784	3.31%	3.31%	3.31%
	Excluding All Outliers	14.27	0.36	1814	14.02	0.35	1783	--	--	--
Group C Test vs. Control Data	Excluding Only Extreme Outliers	15.71	0.39	1997	14.35	0.36	1824	8.66%	8.66%	8.66%
	Excluding All Outliers	15.71	0.39	1997	14.38	0.36	1828	8.47%	8.47%	8.47%

[7] Diesel Net. http://www.dieselnet.com/standards/us/hd.php#pre04.

Analysis Phase	Scenario	Control Emission Rate, grams/mile			Test Emission Rate, grams/mile			% Reduction in Emission Rate		
		NOx	PM	CO_2	NOx	PM	CO_2	NOx	PM	CO_2
Group A Test vs. All Truck Control Data	Excluding Only Extreme Outliers	15.14	0.38	1925	13.63	0.34	1733	9.95%	9.95%	9.95%
	Excluding All Outliers	15.10	0.38	1920	13.50	0.34	1716	10.59%	10.59%	10.59%
Group B Test vs. All Truck Control Data	Excluding Only Extreme Outliers	15.14	0.38	1925	14.03	0.35	1784	7.31%	7.31%	7.31%
	Excluding All Outliers	15.10	0.38	1920	14.02	0.35	1783	7.11%	7.11%	7.11%
Group C Test vs. All Truck Control Data	Excluding Only Extreme Outliers	15.14	0.38	1925	14.35	0.36	1824	5.21%	5.21%	5.21%
	Excluding All Outliers	15.10	0.38	1920	14.38	0.36	1828	4.75%	4.75%	4.75%
All Truck Groups Test vs. Control Data	Excluding Only Extreme Outliers	15.14	0.38	1925	14.05	0.35	1786	7.19%	7.19%	7.19%
	Excluding All Outliers	15.10	0.38	1920	14.04	0.35	1785	6.98%	6.98%	6.98%

Overall, the data suggest a decrease of approximately seven percent in the emission rate of NO_x, PM, and CO_2 based upon an improvement in fuel economy. Additional reductions in PM are attributable to use of the DOC in Groups A and B, which is verified by EPA to result in a reduction in PM emissions of at least 20 percent.

In addition, increases in fuel economy yield fuel savings which are highly valuable to long-haul fleets, as fuel costs are frequently cited as one of the highest costs of business operation. To establish a range of fuel savings potentially realized from this study, gallons saved was estimated from the analysis phases with the lowest and highest statistically significant increases in fuel economy and an estimated annual mileage of 120,000 miles per year, using the following equation.

> Gallons Diesel Saved = (annual mileage/control condition MPG) – (annual mileage/test condition MPG)

The resulting estimate was used to approximate a monetary fuel savings, assuming an average cost of $3.76 per gallon of diesel. This price is based upon the annual cost of on-highway diesel in 2008 for the Gulf States region, as reported by the Energy Information Administration.[8] Table 15 illustrates the fuel savings and associated costs.

[8] Energy Information Administration. http://tonto.eia.doe.gov/dnav/pet/pet_pri_gnd_a_epd2d_pte_cpgal_a.htm.

Table 15: Fuel Savings Estimated from Sagebrush Data

Analysis Phase	Scenario	Control Condition MPG	Test Condition MPG	Annual Gallons of Diesel Saved, per Truck	Approximate Annual Fuel Savings, per Truck
Group B Test vs. Control Condition Data	Excluding Only Extreme Outliers	5.46	5.64	727.10	$2,733.90
Group A Test vs. Control Condition Data	Excluding All Outliers	5.19	5.87	2,659.79	$10,000.81

Although the data show a wide range in fuel savings, the potential for fleet-wide reductions in fuel use and costs are significant even in the more conservative case. The company's costs for installing the upgrade kits technologies were approximately $14,500 per truck for Group A and $8,900 per truck for Group B. Using the annual fuel savings identified above, the technology investments in Group A would pay for themselves in approximately one and one-half years, and those in Group B would yield a return on investment of approximately three years, based upon improvements in fuel economy.

7 Challenges

Many challenges arose during the course of this study; some were expected due to study design, but several were unforeseen. At the root of many of these issues is the variability that is inherent in any real-world, in-use study. This is more pronounced within an industry such as long-haul trucking, which is very dynamic and makes frequent operational changes in response to business needs.

One of the most prominent externalities in this study was the individual truck driver, as drivers changed often. Several critical performance parameters are directly and significantly impacted by driver behavior, including speed, idle time, and frequent stops and starts, all of which have the potential to impact fuel economy. Drivers who maintain lower speeds and fewer starts and stops likely have better fuel economy. Similarly, fuel economy calculated from fuel transactions would be expected to appear higher among drivers who minimize idle time. Anecdotal evidence from Roehl reinforces this difficulty, as the company indicated that during their own evaluation of various technologies (both related to this study and independent efforts) it is difficult to isolate the impact of a particular device due to frequent driver turnover. Additionally, driver behavior may change over time in response to new company initiatives. Roehl initiated performance-based incentive and driver awareness programs over the course of the study which may have impacted certain drivers' habits and Sagebrush had indicated an interest in implementing similar programs during the course of the study.

Additional operational variables include differences in routes and terrain, which may also introduce differences in fuel economy based upon factors such as roadway conditions, speed limits, and changing elevations. Changes in cargo load may also impact fuel economy by introducing variability in weight and engine load. Furthermore, both companies made additional technology investments across their fleets, including the installation of APUs on several control trucks. This potentially impacted the comparison of a test truck to a "control" truck, since the control truck was no longer operating under true baseline conditions. These are items which are difficult to fully control or plan for in a real-world study, as the participating company is compelled to make decisions based upon the best business case.

Another challenge was related to operational difficulties related to the technologies installed. Roehl was surprised to find that of the technologies in their upgrade kit, the APUs presented the most obstacles. Some of these issues were found to be related to maintenance and proper installation, but others were also an issue of driver training on appropriate use of the device and troubleshooting. Because the test trucks were domiciled away from the company terminal, some of these problems lasted several months before being fully resolved. Although the impacts of excessive idling could be isolated through use of the ECM data, this issue is worth noting as a potential complication for data collection efforts.

Sagebrush cited performance concerns with several of their initially selected technologies, including the automatic tire inflation systems, single-wide tires, and crankcase filters. The primary concern related to single-wide tires was the company's feeling that additional driver training should accompany installation, as the tires were reported to perform differently in rainy conditions. The company felt that the need to initiate data collection quickly precluded them from being able to carry out such education for their operators, and they worried about potential safety issues that could result. Challenges related to both the automatic tire inflation systems and crankcase filters appeared to arise from miscommunication and/or an unclear understanding of the appropriate application or installation on the specific truck makes and models. Sagebrush expressed frustration that the configuration of their engines was such that the mounting brackets included with the crankcase filters were not usable, and the company was unable to find a solution for installation. Likewise, the automatic tire inflation systems were apparently engineered for trucks with a different design than those in their fleet, which posed operational difficulties.

Several difficulties that arose through this study were unexpected issues related to the data collected. NCTCOG was surprised to hear both companies claim that ECM fuel economy is considered unreliable, as they believe the ECM to overestimate fuel economy by approximately one to one-and-a-half miles per gallon. If this over-reporting was consistent across all makes and models, it would still allow for fair comparison of different truck data. However, acceptable margins of error differed between manufacturers; this is believed to be the cause of the inconsistency in data from Roehl truck C5 as compared to the rest of the trucks in the study.

Closure of the Sagebrush business was one of the most complicating issues, as it precluded full implementation of the study within its fleet and ultimately resulted in a data set which significantly deviated from the original study design. As the closing occurred unexpectedly during the technology installation phase of the project, NCTCOG was unable to prepare alternate methodologies for data collection and analysis. The differences in the data set received as compared to that called for in the study design necessitated changes in the analysis plan for this group of trucks and precluded useful comparison to the Roehl fleet. Although this information is useful for calculating overall fuel economy, it does not present the level of detail available in ECM downloads, such as speed and idle time. This is especially helpful in separating fuel consumed during idle time and getting a more accurate estimate of over-the-road fuel economy which reflects the efficiency of the truck as a whole.

Sample size is an additional difficulty, particularly related to the ECM-based data. Because of the changes in study design related to Sagebrush, only six test and six control trucks were analyzed using ECM data. Discussion with Roehl indicated that they have seen significant changes in their fleet performance; unfortunately, such changes were not visible in the limited data set available for this study.

Another challenge related to the data set is the accuracy of the fuel transactions. For both companies, fuel transaction logs included a mileage number which was input by the driver. The Roehl fuel transaction data set appeared to be of sound quality, as supported by statistical analysis which revealed a small standard deviation. Company feedback revealed that Roehl maintains several driver incentive and/or performance programs which are based upon fuel efficiency, and each driver's performance data is based upon these fuel logs. This provides an incentive for the drivers to be consistently accurate when entering this information. However, there was a large degree of inconsistency or error within the Sagebrush data, including missing measurements and instances where numbers were clearly keyed inaccurately (i.e. estimates rounded to the nearest thousand, decreases rather than increases in sequential transactions, etc.). Because the fuel transactions became increasingly important during the study, and indeed are the primary source of information from Sagebrush, the accuracy of this data set is critical.

8 Successes

Despite the challenges of this study, several successes were realized. The most notable of these is the increase in fuel economy among the Sagebrush trucks after installation of SmartWay technologies, which indicates that the use of the upgrade kits positively impacted fuel efficiency. Although operational externalities may also impact fuel economy, the data support the assertion that installation of multiple SmartWay technologies yields greater benefits than installing only one, as greater increases were seen among the truck groups with multiple devices installed. This suggests a direct link between the technology installation and MPG increase, particularly as no operational trends are visible in the ECM data set available. These gains correspond to a reduction in emissions which could significantly reduce the environmental impact of this industry if such reductions were accomplished on a widespread basis. In addition, the fuel savings realized through these technologies allow companies to recoup their investments in only a few years.

Roehl reported that they had concerns going into the program regarding mechanical and operational difficulties that may be experienced due to use of the crankcase filters, but during the study they did not experience any complications. Through discussion with the company, it was discovered that they also invested in diesel particulate filters for some of the non-study trucks in its fleet. Though this investment is unrelated to the study, it is worth noting that, as of the date of this report, the company has not experienced any performance-related problems such as back pressure or loss in fuel economy, which it had expected.

The study has already resulted in real-world benefits and emissions reductions through the increased use of idle reduction technology. Early in the installation process, Sagebrush used estimated fuel cost savings associated with the use of APUs based upon the first few units installed; as they forecasted dramatically reduced expenses, the company chose to purchase APUs for its entire fleet. Likewise, Roehl chose to invest in APUs for the majority of its fleet as well, not only the test trucks. This investment will result in ongoing emissions reductions and fuel conservation through the continued use of these devices, which supports the underlying goals of the EPA SmartWay Program.

In particular, Roehl cited this study as an overall positive experience because it facilitated greater awareness and understanding of performance metrics within the company. Prior to this study, the company seldom delved into the ECM data to evaluate performance.

However, the monthly reporting required for this project prompted them to evaluate the information in the ECM download more closely, and they began to scrutinize individual driver and truck performance, especially related to idle time. They have initiated several incentive and performance-based programs linked to reductions in idling and have greatly increased awareness among both fleet managers and individual drivers. The company sites increased ownership of truck efficiency as one of their key elements and has seen an overall increase in fleet-wide efficiency. Though not all improvements are specifically related to the upgrade kits installed through the demonstration project, the knowledge and increased awareness the company has gained is a success in itself.

9 Lessons Learned

Not all of the challenges and complications faced through this study can be avoided in any real-world, in-use evaluation of technologies on Class 8 long-haul trucks. However, there are a few lessons learned which can better prepare all participants in a similar study.

Because both companies cited concerns with the accuracy of fuel economy as reported by the ECM, it is recommended that all future studies maintain collection of fuel transaction data. However, key operational changes such as idle time and speed are not visible if fuel transactions are the only data available. Therefore, it is recommended that ECM data be included as well. Because of the variability in margins of error between different ECMs, it is recommended that all trucks contain the same make of engine to minimize error introduced through these differences.

The dynamic and unpredictable nature of the trucking industry, and its sensitivity to economic uncertainty, necessitates a frequent, continuous line of communication with all industry participants to gain a full understanding not only of technology performance, but also of overall business operations. Routes of travel for trucks under study can change dramatically based upon business conditions, such as the loss or gain of a new customer, which may impact performance data. Driver awareness programs may result in more efficient operations that reflect the impacts of both technological and behavioral changes. Although the variability introduced by these factors, as well as many others that arise in this industry, cannot be avoided, constant communication between investigators and participants can help ensure that they are fully documented to better allow for evaluation of data trends during the analysis phase. In the event an industry participant encounters financial or business difficulty, an ongoing dialogue would also allow investigators to take proactive measures to modify the study design to ensure the collection of the most appropriate information and/or data if necessary.

To alleviate some of the operational externalities that existed in this study, some recommendations are made for future analyses. It may be advantageous for further research to rely more heavily on analysis of the same fleet of trucks before and after installation of SmartWay technologies, as opposed to identifying a fleet of test trucks versus control trucks. By designing a study this way, some of the potential variability between test and control conditions related to individual truck characteristics (i.e., ECM make, age, and overall truck condition) can be minimized. In the case of the participants in this particular study, it also would have reduced some of the route variability that existed between the control and test fleet for Roehl trucks. However, investigators are cautioned to ensure an adequate time frame for data collection. Although a single ECM download may reflect a long period of time, the variance in truck performance over the months or years reflected in that download is unknown. Thus it is recommended that this type of study provide for monthly data collection for 12 months under control conditions, then 12 months under test conditions. Future studies that maintain separate fleets of test and control trucks may benefit from ensuring that both truck groups maintain routes over a wide geographic area. By not targeting trucks with dedicated routes to serve as a test fleet, differences in terrain such as those discussed in this report are minimized. Furthermore, the dynamic nature of the trucking industry is such that industry participants can seldom guarantee dedicated routes over a long period of time. While it may be possible to identify both a test and control fleet with similar dedicated routes at the time the study begins, business conditions may force changes to those routes during the study period.

Clear communication is also necessary with participating fleets regarding expectations or future plans for fleet-wide application of technologies or changes in operational parameters which may impact control trucks included in the study. Both companies in this study installed APUs on control trucks during the course of the study, which had the potential to undermine data collection. Additionally, Roehl reset ECM parameters to reduce allowable speeds and control idle time. Depending on the nature of the study and the partnership established with industry participants, investigators may wish to disallow these types of operational modifications during the course of the study to better control extraneous factors which can influence the performance measure of interest.

Participants also need to ensure that industry partners have a full understanding of the appropriate use and application of new technologies which are being considered. The obstacles encountered by Sagebrush suggest that it may be desirable to involve technology vendors more actively in such studies to provide technical support and/or troubleshooting, and to gain additional insight on operational difficulties.

10 Conclusion

When this study began, the SmartWay program was still very young and SmartWay technologies, particularly fuel-saving devices such as single-wide tires and trailer aerodynamics, were in use among a very small subset of the industry. While these devices have not yet become commonplace among the trucking sector, their use has increased dramatically as the SmartWay Transport Partnership has gained notoriety and welcomed a fast-growing coalition of companies into its ranks. At the same time, the long-haul trucking industry has faced great financial difficulty over the past two years as the economic climate of the country has grown increasingly unstable. As fuel costs are a significant operating expense for these companies, the need for cost-effective investments which can increase fuel efficiency is increasingly important.

Although this report highlights the challenges in conducting a real-world, in-use evaluation of the effectiveness of SmartWay technologies due to the many different influences present in such a study, quantifiable benefits were attributed to the installation of SmartWay technologies. Isolating the impacts of technological factors from operational elements is very difficult. Evaluation of data gathered from the two fleets included in the study yielded very different results. In one case, no clear conclusions could be drawn. The other suggested noticeable fuel economy improvement that appears to be heavily attributable to the installation of technologies. Despite the mixed results from the data, both companies developed a greater awareness of fleet performance that presents an opportunity to achieve additional efficiencies in the future. Additionally, both yielded decreases in fuel consumption and emissions through use of the SmartWay technologies, though these reductions occurred in different ways. NCTCOG anticipates that investment in SmartWay technologies will continue to increase over time and that as the industry seeks to reduce operating costs, it will continue to view the SmartWay program and the tools it promotes as valuable ways to improve fleet efficiency, reduce fuel consumption, and reduce emissions.

Appendices

Appendix A

Quality Assurance Project Plan

QUALITY ASSURANCE PROJECT PLAN

For

Study and Analysis of
Fuel Consumption and Emissions Reductions
For Heavy Duty Diesel Trucks

Prepared by:

Carrie Reese
North Central Texas Council of Governments
Transportation Department

November 30, 2006
Revised: December 13, 2007

Approvals

Signature______________________________ Date 1/8/08
U.S. Environmental Protection Agency Project Officer
Annie Kee, SmartWay Transport Partnership

Signature______________________________ Date 1/14/2008
U.S. Environmental Protection Agency Quality Assurance Manager
Ruth Schenk, Quality Assurance Manager

Signature______________________________ Date 12-13-07
North Central Texas Council of Governments Project Manager
Carrie Reese, Program Manager

Signature______________________________ Date 12-14-07
North Central Texas ~~Council of Governments~~ Project Quality Assurance Manager
Madhusudhan Venugopal, Senior Transportation Planner

QUALITY ASSURANCE PROJECT PLAN ELEMENTS

Table of Contents

A. PROJECT MANAGEMENT

A3. Distribution List

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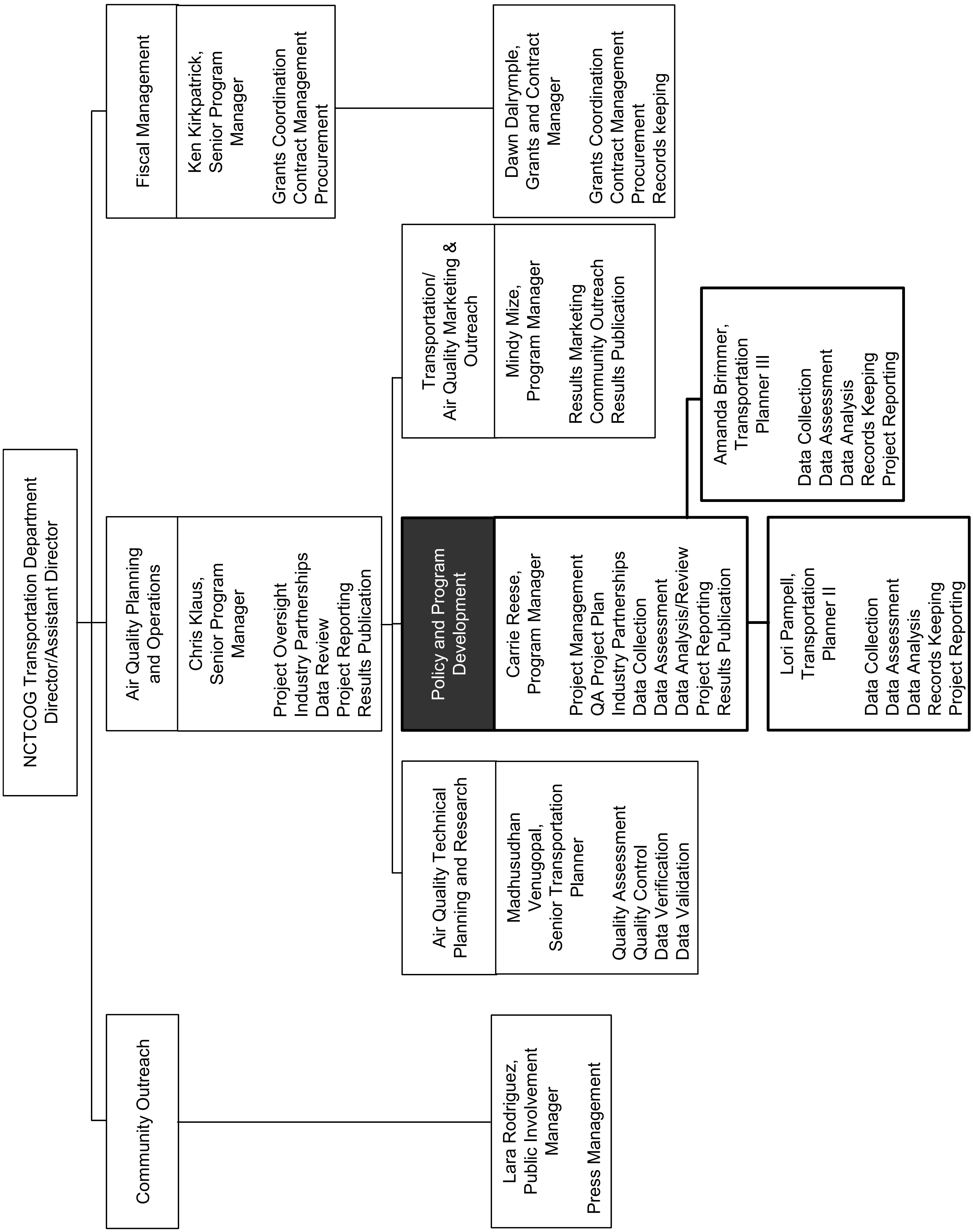
A4. Project/Task Organization

The following organization chart identifies participating NCTCOG staff and their associated responsibilities. Primary project staff is the Air Quality Policy & Program Development Team.



NCTCOG Transportation Department
Director/Assistant Director
Fiscal Management
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Grants Coordination
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Procurement
Dawn Dalrymple, Grants and Contract Manager
Grants Coordination
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Procurement
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Chris Klaus, Senior Program Manager
Project Oversight
Industry Partnerships
Data Review
Project Reporting
Results Publication
Transportation/ Air Quality Marketing & Outreach
Mindy Mize, Program Manager
Results Marketing
Community Outreach
Results Publication
Policy and Program Development
Carrie Reese, Program Manager
Project Management
QA Project Plan
Industry Partnerships
Data Collection
Data Assessment
Data Analysis/Review
Project Reporting
Results Publication
Amanda Brimmer, Transportation Planner III
Data Collection
Data Assessment
Data Analysis
Records Keeping
Project Reporting
Lori Pampell, Transportation Planner II
Data Collection
Data Assessment
Data Analysis
Records Keeping
Project Reporting
Air Quality Technical Planning and Research
Madhusudhan Venugopal, Senior Transportation Planner
Quality Assessment
Quality Control
Data Verification
Data Validation
Community Outreach
Lara Rodriguez, Public Involvement Manager
Press Management

A5. Problem Definition/Background

The SmartWay Transport Partnership (SmartWay), established by the U.S. Environmental Protection Agency (EPA) in 2004, is a voluntary, public-private partnership with the ground freight industry. Truck and rail freight is integral to the nation's economy; however, heavy-duty diesel vehicles are major consumers of fossil fuels and major contributors to air pollution. The SmartWay Transport Partnership promotes a variety of strategies designed to reduce energy consumption and vehicle emissions that also lead to a reduction in costs for truck and rail freight operators.

One current strategy is to incorporate technologies on heavy-duty diesel trucks that reduce fuel use and emissions. EPA has recommended use of the following technologies in the SmartWay program: single-wide tires, automatic tire inflation, advanced trailer aerodynamics, nitrogen oxide (NOx) reflash, lube viscosity, mobile idle reduction technologies and emission control technologies such as diesel oxidation catalysts, crankcase filters and diesel particulate filters. EPA also anticipates that these technologies may be most effective if utilized together in an overall kit design.

Implementation of these technologies by trucking companies has been discouraged by up-front capital costs and access to affordable financing. In order to purchase these technologies, truck owners need confirmation of fuel cost savings to assure a return for their investment. Likewise, financial institutions are more willing to offer loan packages for technologies with documented financial savings. In addition, state governments have not historically focused financial or other support on long-haul freight emissions, due to this fleet traveling across state boundaries.

Demonstration of fuel savings and emissions reductions gained from these technologies under real operating conditions may lead to greater investment in them, ultimately leading to greater adoption and use. NCTCOG will partner with EPA to perform the following activities to demonstrate the effectiveness of the SmartWay technology upgrade kit.

A6. Project/Task Description

<u>Task 1. Identify Trucking Company Partners</u>
NCTCOG will solicit interest from commercial trucking companies with Class 8 Heavy-Duty Vehicles to participate in the demonstration project. A competitive selection process, or Call for Projects, will be conducted to determine the number of freight partners and the appropriate mix of operational characteristics. As the effectiveness of certain technologies vary depending on operational characteristics, evaluation of the technologies under a wide variety of conditions is essential. Interested trucking companies will be required to include operational factors in their response to NCTCOG's solicitation of interest. The operational factors to be considered for a complete evaluation include, but are not limited to: geographic terrain, temperature, speed, freight type/payload, length of haul and location of operation. EPA will be consulted on final selection of fleet partners.

Additional criteria for eligibility include trucking companies that:

- Are based in a nonattainment or maintenance area, and/or operate in the Dallas-Fort Worth Metroplex or near the U.S.-Mexico border,

- Are willing to contribute at least 50% of the capital costs towards fuel-saving and mobile idle reduction technologies,
- Are willing to maintain a SmartWay tractor-trailer combination throughout the duration of the study period, or create trailer pools whereby a SmartWay trailer is always available at the drop-off or pick-up location,
- Are able to maintain and track fuel economy in a consistent and reliable manner,
- Travel consistent, dedicated routes over long distances,
- Own trucks already equipped with SmartWay technologies,
- Will include fuel economy data from a sampling of trucks traveling similar routes as the test vehicles, but which are not equipped with SmartWay technologies to provide a baseline for comparison,
- Are willing to provide other project data such as fuel logs, fuel receipts, truck/engine information and characterization of operations, and
- Are committed to operating, maintaining, and supporting SmartWay upgrade kit technology.

Deliverables: Agreements with the appropriate number of trucking companies exhibiting a wide range of operational characteristics

Task 2. Technology Procurement and Installation

NCTCOG will comply with policies required by the agency and by EPA (i.e. Federal Acquisition Regulations) regulations for competitive procurements to ensure fairness and cost-effectiveness. NCTCOG will work with trucking companies to procure and install SmartWay upgrade kit technologies from appropriate vendors. EPA has specified the following technologies for the demonstration project:

Technology	Estimated Cost
Fuel-saving technologies	
Single-wide tires	$5,600
Automatic tire inflation	$900
Advanced trailer aerodynamics	$2,400
NOx Reflash (MY 1993-1998)	$0
Low viscosity lubricants	---
Mobile idle reduction technologies	
Bunk heater	$1,500
Auxiliary power unit	$8,500
Emission control technologies	
Diesel oxidation catalyst	$1,200
Crankcase filter	$1,900
Diesel particulate matter filter	$8,000-$10,000

SmartWay upgrade kits installed on test vehicles will include: one or more of the fuel-saving technologies, one mobile idle reduction technology and one emission control technology. Preference would be for each kit to contain both single-wide tires and advanced trailer aerodynamics at a minimum. In order to increase the cost-effectiveness of the demonstration and maximize the number of participating vehicles, NCTCOG will seek 50% contribution towards the cost of the fuel-savings and mobile idle reduction technologies. NCTCOG will cover 100% of the emission control technology cost. NCTCOG will seek discounts, donations and free installation services from technology vendors. This information will be provided to potential fleet partners during the Call for Projects. At the end of the study period, all equipment will be 100% vested with the fleet partners.

Deliverables: Procurement and installation of appropriate SmartWay upgrade kit technologies on each participating truck

Task 3. Data Collection

NCTCOG will require that the freight carrier partners provide the following standard vehicle information for each participating truck: Vehicle Identification Number, Gross Vehicle Weight Rating, engine make, engine model year and certified engine standard. Certain information about the engine control module will also be requested.

Upon installation of the SmartWay upgrade kit technologies, freight carriers will be expected to report to NCTCOG on a monthly basis: fuel economy data obtained from the engine control module, supporting documentation such as fuel logs and fuel receipts, and any operational characteristics as required by the project. NCTCOG will work with fleet partners to determine the most convenient and accurate method for conveying the supporting documentation. Trucking companies will submit data for both test trucks and control trucks.

Deliverables: Complete fuel economy and operating characteristics data for each participating and control truck

Task 4. Evaluate Fuel Savings and Emissions Reduction

NCTCOG will analyze fuel economy data collected from both the test trucks and control trucks. Included in the analysis will be consideration of trends correlated to various operating characteristics and combinations of upgrade kit technologies. An assessment of cost savings through use of the technologies will also be conducted.

NCTCOG will use EPA-approved fuel-to-emission conversion factors and verified reductions from emission control technologies to determine overall nitrogen oxide (NOx) emissions reductions achieved by the upgrade kits. NCTCOG will explore estimating particulate matter (PM) reductions with EPA.

Deliverables: Estimation of fuel-savings and emissions reductions from installation of SmartWay upgrade kit technologies

Task 5. Publicize Demonstration Project Results

NCTCOG has many opportunities in which to educate the ground freight industry, state and local government partners, and the general public on the findings of the demonstration project. NCTCOG will present the results of the demonstration project at meetings of the North Texas Clean Air Steering Committee; Regional Transportation Council (RTC); RTC Air Quality Subcommittee; RTC Intermodal, Freight and Safety Subcommittee; and Clean Cities Technical Coalition. NCTCOG also hosts quarterly public meetings at various locations within the Metroplex. NCTCOG staff is very active in transportation and air quality professional organizations, often presenting at meetings and national conferences. NCTCOG will seek opportunities to present results to ground freight industry organizations such as North America's

Supercorridor Coalitions and the Texas Motor Transportation Association. NCTCOG regularly sends press releases to over 200 media outlets. Press releases very often lead to radio and television interviews.
NCTCOG will also include information on the demonstration project in agency publications. *It's Your Region* is a newsletter distributed monthly to 4,000 North Central Texas citizens. *Mobility Matters* is mailed quarterly to approximately 8,000 subscribers with an additional 2,000 copies distributed at various public meetings. NCTCOG will seek out opportunities to submit findings to transportation, air quality and ground freight industry publications. Additionally, NCTCOG will publish findings on the agency website to reach our electronic audience. The NCTCOG website averages 1,000 visits per day.

Deliverables: Various presentations and publications to announce the results of the SmartWay upgrade kit demonstration project

Schedule
The SmartWay upgrade kit demonstration project will conclude in 22 months time.

Task	Estimated Timeframe
Task 1. Identify Trucking Company Partners	December 2006-April 2007
Task 2. Technology Procurement and Installation	April 2007-July 2007
Task 3. Data Collection	August 2007-August 2008
Task 4. Evaluate Fuel Savings/Emissions Reduction	September 2008-October 2008
Task 5. Publicize Demonstration Project Results	October 2008 and thereafter
Final Report	October 2008

A7. Quality Objectives and Criteria

Data Quality Objectives (DQO) are identified through EPA's recommended systematic planning process for determining the type, quantity and quality of data sufficient to support the goals of a study and to produce credible results. Valid data of known and documented quality is needed to estimate the average improvement in fuel economy and fuel cost savings through installation of EPA SmartWay Kit technologies on heavy-duty diesel trucks. The actual fuel consumption and reductions cannot be established until testing is concluded; therefore, this document does not adopt explicit quantitative or predetermined DQOs. However, the fuel economy data retrieved from the engine control modules must meet specified performance criteria to minimize the possibility of erroneous conclusions and to maintain an acceptable level of estimation uncertainty. The performance criteria are expressed as the following Data Quality Indicators.

Precision
Precision is the measure of agreement among repeated measurements of the same property under identical or substantially similar conditions and is an indicator of the random errors or fluctuations in the measurement process. The precision for data collected from each sampling unit (one truck) will be evaluated by calculating the standard deviation with confidence interval for measurements to determine the range of sample variability. The data points obtained per

truck is anticipated to be relatively uniform, so larger standard deviations indicating imprecision will be investigated for flaws in the measurement procedure.

Bias

Bias is the measure of the magnitude of systematic or persistent distortion of a measurement process that causes error in one direction. The principal causes of bias include incomplete data, analytical errors and sampling errors. The design of this study excludes most traditional analytical errors, but specifications for calibration of the engine control modules will be included in the study design. The sampling scheme was developed to insure the maximum amount of randomness achievable within the constraints of the study and to protect against introduction of judgment. The study as designed is expected to achieve a 100% response rate from each sampling unit with a ten percent margin for loss of data due to inoperation of a test truck.

Representativeness

Representativeness is the measure of the degree to which data is suitable to represent a characteristic of a well-defined population. Sample size for this study is determined by budgetary restrictions; however the inclusion of 30-50 test trucks and a number of control trucks is not inconsistent with many technology demonstration projects currently being conducted. While there are many heavy-duty diesel trucks nationwide and there are many engine and body combinations, the target population can be assumed to be relatively homogenous in relation to fuel consumption which will help to increase sample representativeness. Estimates also appear to support this relative homogeneity historically across model years for weight classes 8A and 8B as provided by U.S. EPA in *Updating Fuel Economy Estimates in MOBILE 6.3, EPA420-P-02-005, August 2002*.

Projected Diesel Heavy-Duty Vehicle Fuel Economies (mpg)
Model Year Weight Classes:

Year	2b	3	4	5	6	7	8A	8B
83	11.13	10.01	9.27	8.78	7.96	7.38	5.79	5.16
84	11.27	10.14	9.34	8.87	8.02	7.39	5.84	5.25
85	11.41	10.27	9.41	8.95	8.08	7.40	5.90	5.33
86	11.55	10.39	9.49	9.04	8.14	7.41	5.96	5.42
87	11.69	10.52	9.56	9.12	8.20	7.43	5.96	5.51
88	11.83	10.65	9.63	9.21	8.25	7.44	6.03	5.59
89	11.97	10.77	9.70	9.29	8.31	7.45	6.10	5.68
90	12.11	10.90	9.77	9.38	8.37	7.46	6.17	5.77
91	12.26	11.03	9.85	9.46	8.42	7.47	6.24	5.86
92	12.40	11.15	9.92	9.54	8.48	7.48	6.31	5.95
93	12.54	11.28	9.99	9.63	8.54	7.49	6.38	6.03
94	12.68	11.41	10.06	9.71	8.59	7.51	6.45	6.12
95	12.82	11.53	10.13	9.80	8.65	7.52	6.52	6.21
96	12.96	11.66	10.20	9.88	8.71	7.53	6.59	6.30

Completeness

Completeness is the measure of the amount of valid data obtained from a measurement system. The study design requires a 90% return of prescribed measurements from 100% of the sampling units. In the case that full return of valid data is not achieved, an assessment will occur to determine if additional sampling is required or if other corrective actions may be made.

Comparability

Comparability is the measure of confidence that two or more data sets may contribute to a common analysis and is an indication of the similarity of attributes of the data sets. Measurements will be taken from sampling units over the same time period using the same methodology and reported in a common metric. However, measurements will likely be taken with different engine control module models. An investigation into potential differences may be necessary to ensure measurement comparability.

Sensitivity

Sensitivity is the capability of a method or instrument to discriminate between measurement responses representing different levels of the variable of interest. There is no currently defined level of interest for detecting or measuring fuel economy by engine control modules. If sensitivity becomes an apparent issue in the course of the study, it will be addressed accordingly.

A8. Special Training/Certifications

The project tasks will be performed by experienced NCTCOG staff. No special training or certifications are required for staff implementing this project.

A9 Documentation and Records

The following documents are required to fulfill the objectives of this study:

Quality Assurance Project Plan

The NCTCOG Project Manager will be responsible for distributing and maintaining the Quality Assurance Project Plan (QAPP). All project staff will be provided with hard copies of the document and the location of the current electronic copy. Any revisions to the QAPP will be numbered sequentially. Signature upon receipt of the original version, as well as any revision, will be required.

Analytical Report

NCTCOG will provide the EPA Project Officer with a final analytical report, including narratives on study purpose and goals; tasks and analyses performed; study results and discussion; and quality assurance considerations. Raw data will be included in an appendix. The EPA Project Manager will review and comment on all reports prepared in this study prior to publication. NCTCOG shall make final decisions on content.

B. DATA GENERATION AND ACQUISITION

B1. Sampling Process Design (Experimental Design)

Within budgetary constraints, it is expected that 30-50 test trucks will be upgraded with fuel-saving and emission-reducing technologies. While sample sizes can be larger, and many are smaller, the sample size for this project is comparable to previous technology demonstration and evaluation studies conducted by reputable agencies. A few examples of such studies include:

Agency	Study	Sample Size
California Air Resources Board	BP Emission Control Diesel Demonstration, 2000 (arb.ca.gov/diesel/Mobile/BPdemo.PDF)	15-30 per vehicle type
U.S. Department of Energy	New York City Hybrid and CNG Transit Buses, 2006 (www.eere.energy.gov/afdc/progs/vwbs2.cgi?9758)	20
U.S. Environmental Protection Agency	Beijing Clean Diesel Retrofit Demonstration, 2005 (www.epa.gov/otaq/retrofit/china2.htm)	25-30
National Renewable Energy Laboratory	Idle Reduction Technology Demonstration, 2003 (www.avt.nrel.gov/pdfs/demo_plan_final.pdf)	30

Selection of fleet partners and test trucks will be made through a competitive Call for Projects. While certain eligibility criteria must be met by fleet partners and certain decisions must be made to include a variety of operating conditions in the sample group, selection will be made to ensure as much of a probability-based design as possible. The open solicitation itself will impart randomness to the sample design.

Measurement of average daily fuel economy for each test truck will be taken from the engine control module for one year equaling a maximum of 260 data points per sampling unit. It is understood, however, that each truck may not operate every day of the year, so a ten percent loss of data per sampling unit will be allowed, equaling a minimum of 234 data points for each sampling unit. Measurements should be taken as consistently as possible at the same time of the day. Data collection over a 12-month period will enable the project team to account for seasonal differences as necessary. Additionally, at least one control truck must be included to represent each route a test truck is traveling. Measurements from the control trucks are subject to the same frequency and conditions as required of the test trucks.

Fleet partners will also be required to submit documentation on a monthly basis to support fuel economy measurements such as fuel logs and/or fuel receipts. Information on fuel quantity and mileage will be included and should be recorded, at a minimum, upon each refueling. Additional data to support claims regarding operational characteristics may also be deemed necessary as the project progresses.

B2. Sampling Methods

No standard operating procedures have been developed for collection of data as required by this project. The engine control module in a sampled truck will continuously monitor engine and vehicle operations providing data to derive an average daily fuel economy measurement. In responding to the Call for Projects, fleet partners will include a discussion of how the data will be averaged, stored, downloaded and reported. During each monthly collection period, fleet partners will be responsible for identifying any problems that may arise, take the necessary corrective measures, and report such issues and actions to NCTCOG. Fleet partners should also maintain records of data collected for the duration of the study period.

During data collection, the NCTCOG project team will continue to consider the following questions as the basis for corrective action:

- Is the correct data being collected?
- Do better methods of data collection exist?
- Is the data behaving as expected?

B3. Sample Handling and Custody

Fleet partners will identify the person(s) responsible for engine control module data collection, averaging and transmittal to the NCTCOG Project Manager or other project designee. Each measurement should include the following identifiers: fleet name, truck VIN, date, time, name of collector. Fleet partners will also identify the person responsible for maintenance and supervision of fuel logs and fuel receipts. These documents should include the following identifiers, as appropriate: fleet name, truck VIN, date, time, name/initials of person making the entry. The NCTCOG project team will document the monthly transmittals of data from the fleet partners.

B4. Analytical Methods

The difference in fuel use and nitrogen oxide (NOx) emissions between test trucks and control trucks will be estimated in several phases:

- An estimation of difference between composite fuel economy and NOx emissions for fleet-specific test trucks versus their identified control truck counterparts,
- An estimation of difference between composite fuel economy and NOx emissions for individual truck bins versus the entire control truck population, and
- An estimation of difference between composite fuel economy and NOx emissions for the entire test truck population versus the entire control truck population.

The analytical methodology, identical for all phases of estimation, is as follows:

Calculate Composite Fuel Economy

The sample mean for the population of interest will be calculated to derive the composite fuel economy for that population. The standard deviation of the sample mean, along with confidence interval, will be calculated to determine the dispersion of the data set. These functions will be automated in Microsoft Excel; however, the theory is outlined below.

Where n = sample size,

(Sample Mean) $$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

(Standard Deviation) $$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1}}$$

(Confidence Interval) $$\overline{x} = \pm(zcriticalvalue)\cdot\frac{\sqrt{s}}{n}$$, $\alpha = 0.05$

Determination of Population Distribution

Foremost, the population distribution must be tested for normality to indicate use of parametric or nonparametric statistical tools. Initially, a frequency histogram of fuel economy data will be developed as a visual method for identifying the underlying distribution. If additional verification of normality is required, the Studentized Range Test (SRT) will be utilized. This method compares the sample range to the standard deviation using the SRT critical values, included as Appendix 1. These functions will be automated in Microsoft Excel; however, the theory is outlined below.

(SRT statistic) $a > R = w/s > b$ (indicates normal distribution)

Where,
w = sample range (x_{30}-x_1)
s = sample standard deviation
a = lower critical value
b = upper critical value

Comparison of Populations (Parametric Methodology)

In the case that the data set exhibits a normal distribution, the statistical tool to compare the test truck population against the control truck population is the Two-Sample t-Test. It is assumed at this point that the test truck sample data and the control test sample data will have similar variances. If during the course of analysis, this is determined to be false, alternate methodologies will be explored. This function will be automated in Microsoft Excel; however, the theory is outlined below. When determined to be statistically significant, the estimated difference in fuel economy will be reported as overall percentage change.

Pooled Standard Deviation $$s_p = \sqrt{\frac{(m-1)\cdot s_X^2 + (n-1)\cdot s_Y^2}{m+n-2}}$$

Null Hypothesis H_0: $\mu_x - \mu_y = \delta_0$

Alternative Hypothesis H_A: $\mu_x - \mu_y \neq \delta_0$

Test Statistic $$t_0 = \frac{\left(\overline{X} - \overline{Y} - 0\right)}{s_p\sqrt{\frac{1}{m}+\frac{1}{n}}}$$

Identifying the critical value, $t_{m+n-2,\ 1-\alpha/2}$, from Appendix 2 — reject H_0 if $|t_0| > t_{m+n-2,\ 1-\alpha/2}$.

If H_0 is not rejected, calculate false acceptance error rate, where both m, n are at least: $$\frac{2s_p^2\left(z_{1-\alpha'} + z_{1-\beta}\right)^2}{\delta_{1-}\delta_0} + \frac{z_{1-\alpha'}^2}{4}$$ where, $\alpha' = \alpha/2$

Confidence Interval $$\left(\overline{X} - \overline{Y}\right) \pm t_{m+n-2,1-\alpha/2}\cdot s_p\sqrt{\frac{1}{m}+\frac{1}{n}},$$
with $t_{m+n-2,\ 1-\alpha/2}$

Comparison of Population Fuel Economy (Nonparametric Methodology)

In the case that the data set exhibits a distribution other than normal, the statistical tool to compare the test truck population against the control truck population is the Wilcox Rank Sum Test. It is assumed at this point that the test truck sample data and the control test sample data will have similar variances. If during the course of analysis, this is determined to be false, alternate methodologies will be explored. This function will be automated as much as possible in Microsoft Excel; however, the theory is outlined below. When determined to be statistically significant, the estimated difference in fuel economy will be reported as overall percentage change.

Rank the pooled data from smallest to largest assigning average rank to ties.

Sum the rank of the first population, denoted by R_1. Compute: $$W_0 = R_1 - \frac{m(m+1)}{2}$$

Null Hypothesis H_0: $\mu_x - \mu_y = 0$

Alternative Hypothesis H_A: $\mu_x - \mu_y \neq 0$

Test Statistic

$$z_o = \frac{W_0 - mn/2}{\sqrt{\mathrm{var}(W_0)}}$$, where

$$\mathrm{var}(W_0) = \frac{mn(m+n+1)}{12} - \left\{ \frac{mn}{12(m+n)(m+n+1)} \sum_{j=1}^{g} t_j (t_j^2 - 1) \right\}$$

and where,
g is the number of tied groups
t_j is the number of ties in the j^{th} group

Identifying the critical value, $t_{1-\alpha/2,}$ from Appendix 3

reject H_0 if $|z_0| > t_{1-\alpha/2}$.

If H_0 is not rejected, calculate false acceptance error rate, where both m, n are at least:

$$1.16 \cdot \frac{2 \cdot \mathrm{var}(W_0)\left(z_{1-\alpha'} + z_{1-\beta}\right)^2}{\delta_1^2} + \frac{z_{1-\alpha'}^2}{4}$$

where, α' = α/2

Calculate Nitrogen Oxide Emission Reduction

Reductions in nitrogen oxide (NOx) emissions will be translated from composite fuel economy using the Energy Consumption Factors (ECF) in Appendix 4. Additional reductions, credited to the emission control technology, will be deducted based upon a verified percentage emission reduction, other EPA-accepted percentage emission reduction, or EPA-accepted default percentage emission reduction. This function will be automated in Microsoft Excel; however, the general theory is outlined below.

Control Trucks = Certified Engine Standard x Inverse of Fuel Economy x ECF (g/mi)

$$\frac{g}{bhp-hr} \times \frac{gal}{miles} \times \frac{bhp-hr}{gal} = \frac{g}{mi} NOx$$

Test Trucks = Certified Engine Standard x Inverse of Fuel Economy x ECF x % reduction (g/mi)

$$\frac{g}{bhp-hr} \times \frac{gal}{miles} \times \frac{bhp-hr}{gal} \times \%reduction = \frac{g}{mi} NOx$$

(Where, ECF is understood to be Fuel Density (lb/gal) / Brake Specific Fuel Consumption (lb/bhp-hr) = bhp-hr/gal.)

B5. Quality Control

Quality control for data per sample unit will be based upon the calculation of standard deviation, with confidence interval, to identify any imprecision. Variance will also naturally be derived in this process. Formulas for this quality control process have been defined elsewhere in this document. Quality control will be performed by the NCTCOG project team upon monthly receipt of data from fleet partners. Comparison of engine control module data to fuel logs and fuel receipts will also be performed at this time. If unexpected data values are received, the project team will work with the fleet partner to identify a cause and determine any corrective actions.

B6. Instrument/Equipment Testing, Inspection, and Maintenance

Fleet partners will be responsible for testing, inspecting and maintaining the integrity of the engine control modules per manufacturer recommendations. Fleet partners will be required to summarize any recommended procedures and frequency of implementation in their proposal. These activities will be reported monthly to NCTCOG.

B7. Instrument/Equipment Calibration and Frequency

Fleet partners will be responsible for calibration of engine control modules, as necessary, to manufacturer's specifications. Fleet partners will be required to summarize the recommended procedures and frequency of implementation in their proposal. These activities will be reported monthly to NCTCOG.

B8. Inspection/Acceptance for Supplies and Consumables

No specific supplies or consumables are required for this study.

B9. Nondirect Measurements

NCTCOG will work with fleet partners to determine the most appropriate source of information to help validate the engine control module measurements such as fuel receipts and fuel logs. These data sources will be considered for variability, completeness and comparability to the sample measurements.

B10. Data Management

The records for this project will include miscellaneous correspondence, a sample measurement database, data reports, fleet reports and additional verification data (fuel logs, fuel receipts, etc). Project records will be maintained by the NCTCOG Project Manager in a central hard-copy file and housed on the NCTCOG network server with nightly back-ups. NCTCOG will maintain project records for at least five years, and the EPA Project Manager will be consulted before they are disposed. Project data will be maintained by fleet partners for at least the life of the project.

Computers compatible with Microsoft Office software will be used by the NCTCOG project team for all calculations. No other special data handling equipment or software will be needed for data management.

C. ASSESSMENT AND OVERSIGHT

C1. Assessments and Response Actions

Technical Systems Audits

Technical systems audits will be performed monthly by the NCTCOG Project Manager and QA Manager by responding to project reporting requirements specified by EPA. These audits will determine whether:

- Environmental data collection activities and related results comply with the project's QAPP,
- The procedures defined in the QAPP are implemented effectively, and
- The procedures are sufficient and adequate to achieve the QAPP data quality goals.

Audit of Data Quality

The NCTCOG QA Manager will oversee and document an Audit of Data Quality (ADQ) of at least 10% of the project on a monthly basis. The ADQ will include:

- Verification of data reported by engine control modules
- Review of intermediate calculations, and
- Review of study statistics.

Corrective Actions

All NCTCOG personnel assigned to the project will be responsible for ensuring that the QAPP is implemented, that the sample data is within acceptable limits, and that corrective actions are taken when appropriate. Corrective actions include:

- Identification of the problem,
- Identification of the cause,
- Documentation of any problem,
- Development of a corrective action plan,
- Verification that corrective action was taken, and
- Recommendation of any changes to avoid repeat problems.

The NCTCOG Project Manager and QA Manager will be responsible for documentation and reporting of corrective actions.

C2. Reports to Management

Quarterly Project Reports

The NCTCOG Project Manager or designee will submit quarterly progress reports to the EPA Project Officer within 30 days after each reporting period. These reports shall cover work status, work progress, difficulties encountered, preliminary data results, quality assessment results and a statement of activity anticipated during the subsequent reporting period, including a description of equipment, techniques, and materials to be used or evaluated. A discussion of expenditures along with a comparison of the percentage of the project completed to the project schedule and an explanation of significant discrepancies shall be included in the report.

Final Project Report

The NCTCOG Project Manager or designee will submit to the EPA Project Manager within 90 days after the expiration or termination of the approved project period a final report and at least one reproducible copy suitable for printing. The final report shall document project activities over the entire project period and shall include brief information on each of the following areas: 1) a comparison of the actual accomplishments with the anticipated outputs/outcomes specified in the work plan; 2) reasons why anticipated outputs/outcomes were not met; and 3) other pertinent information, including when appropriate, analysis and explanation of cost overruns or other high unit costs.

Audit of Data Quality Reports

The NCTCOG QA Manager will document and submit results of monthly Audits of Data Quality to the NCTCOG Project Manager. A summary of this information will be included with the quarterly project reports to EPA.

D. DATA VALIDATION AND USABILITY

D1. Data Review, Verification and Validation

Data will be reviewed and accepted if they meet the following criteria:

- Engine control module data is complete,
- Engine control module data was validated and assessed for meeting data quality indicators,
- Actual sample procedures correspond to the proposed sample procedures described in this QAPP,
- Sample handling and chain of custody procedures correspond to the proposed procedures described in this project plan,
- Analysis procedures correspond to the proposed procedures described in this QAPP.

If the data fails to meet the criteria, it will be documented by the NCTCOG Project Manager. Any flagged data will be discussed with the NCTCOG and EPA project teams to determine if the data point will be rejected and if re-sampling is necessary.

D2. Verification and Validation Methods

Data Verification

Data verification is the process of evaluating the completeness, correctness, and conformance/ compliance of a specific data set against the method, procedural, or contractual requirements.
The goal of data verification is to ensure and document that the data are what they purport to be, that is, that the reported results reflect what was actually done. A “certification statement”, signed by the responsible party, will be included to indicate the data have been verified. When deficiencies in the data are identified, then those deficiencies should be documented for the data user’s review and, where possible, resolved by corrective action.

Verification of data will be performed on several levels throughout the study period: by the fleet partners upon collection, by the NCTCOG project team upon receipt and during analysis and finally by the NCTCOG QA Manager during the Audits for Data quality. The second step of this process involves verification of study records to determine that all steps of the study such as sample collection, sample receipt, and sample analysis is conducted according to the QAPP. Such verification will be conducted continuously by the NCTCOG Project Manager. Any variance should be reported.

The product from data verification is an analytical data package that will be submitted to the NCTCOG QA Manager for data validation.

Data Validation

Data Validation is an analyte- and sample- process that extends the evaluation of data beyond method, procedural, or contractual compliance (i.e., data verification) to determine the analytical quality of a specific data set. The main focus of data validation is determining data quality in terms of accomplishment of measurement quality objectives. Upon receipt of the analytical data package, the NCTCOG QA Manager will perform the following steps of data validation:

- Evaluate the field records for consistency,
- Review quality assessment information for engine control module measurements,
- Summarize deviations and determine impact on data quality,
- Summarize samples collected,
- Review data verification records to determine method, procedural, and contractual required QC compliance/non-compliance,
- Review verified, reported sample results collectively for the data set as a whole,
- Summarize data and QC deficiencies and evaluate the impact on overall data quality, and
- Prepare analytical data validation report.

The report will reflect all details of data validation. A discussion of the objectives for sampling and analysis activities and a summary of the needs that the data validator gleaned from the planning documents should be included. Documentation from data validation of field data and analytical laboratory data should also be included in the report. The data validation report should emphasize any deficiencies encountered and clearly describe the impact of such deficiencies on overall data quality. Any updates and/or corrections that were made to the validated data from the original verified data transfers should also be summarized and explained. The report describing the data validation process should provide sufficient detail for the data user to have an overall idea of the quality of the data and how well the project needs were met.

D3. Reconciliation with User Requirements

The final assessment of data quality of this project is a determination of data adequacy to estimate fuel use and emission reductions from the implementation of SmartWay upgrade kits. Statistical analysis of error has been included throughout the project design. Examples include analysis for outliers, dispersion and deviation. This data will be presented to the EPA Project Manager in graphical or tabular form as appropriate. Additionally, the NCTCOG project team will provide a narrative discussion of potential error during data collection and analysis. In this manner, EPA will be able to make appropriate decisions regarding use of collected data and analyzed results in promoting the objectives of the SmartWay Transport Partnership.

APPENDICES

Appendix 1. Critical Values for the Studentized Range Test

	Level of Significance α					
	0.10		0.05		0.01	
n	a	b	a	b	a	b
3	1.78	2.00	1.76	2.00	1.74	2.00
4	2.04	2.41	1.98	2.43	1.87	2.45
5	2.22	2.71	2.15	2.75	2.02	2.80
6	2.37	2.95	2.28	3.01	2.15	3.10
7	2.49	3.14	2.40	3.22	2.26	3.34
8	2.59	3.31	2.50	3.40	2.35	3.54
9	2.68	3.45	2.59	3.55	2.44	3.72
10	2.76	3.57	2.67	3.69	2.51	3.88
11	2.84	3.68	2.74	3.80	2.58	4.01
12	2.90	3.78	2.80	3.91	2.64	4.13
13	2.96	3.87	2.86	4.00	2.70	4.24
14	3.02	3.95	2.92	4.09	2.75	4.34
15	3.07	4.02	2.97	4.17	2.80	4.44
16	3.12	4.09	3.01	4.24	2.84	4.52
17	3.17	4.15	3.06	4.31	2.88	4.60
18	3.21	4.21	3.10	4.37	2.92	4.67
19	3.25	4.27	3.14	4.43	2.96	4.74
20	3.29	4.32	3.18	4.49	2.99	4.80
25	3.45	4.53	3.34	4.71	3.15	5.06
30	3.59	4.70	3.47	4.89	3.27	5.26
35	3.70	4.84	3.58	5.04	3.38	5.42
40	3.79	4.96	3.67	5.16	3.47	5.56
45	3.88	5.06	3.75	5.26	3.55	5.67
50	3.95	5.14	3.83	5.35	3.62	5.77
55	4.02	5.22	3.90	5.43	3.69	5.86
60	4.08	5.29	3.96	5.51	3.75	5.94
65	4.14	5.35	4.01	5.57	3.80	6.01
70	4.19	5.41	4.06	5.63	3.85	6.07
75	4.24	5.46	4.11	5.68	3.90	6.13
80	4.28	5.51	4.16	5.73	3.94	6.18
85	4.33	5.56	4.20	5.78	3.99	6.23
90	4.36	5.60	4.24	5.82	4.02	6.27
95	4.40	5.64	4.27	5.86	4.06	6.32
100	4.44	5.68	4.31	5.90	4.10	6.36
150	4.72	5.96	4.59	6.18	4.38	6.64
200	4.90	6.15	4.78	6.39	4.59	6.84
500	5.49	6.72	5.47	6.94	5.13	7.42
1000	5.92	7.11	5.79	7.33	5.57	7.80

Source: U.S. Environmental Protection Agency, *Data Quality Assessment: Statistical Methods for Practitioners, EPA QA/G-96 (2006)*

Appendix 2. Critical Values of Student's t-Distribution

Degrees of Freedom	1 - α								
	0.70	0.75	0.80	0.85	0.90	0.95	0.975	0.99	0.995
1	0.727	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657
2	0.617	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925
3	0.584	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841
4	0.569	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604
5	0.559	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032
6	0.553	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707
7	0.549	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499
8	0.546	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355
9	0.543	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250
10	0.542	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169
11	0.540	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106
12	0.539	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055
13	0.538	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012
14	0.537	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977
15	0.536	0.691	0.866	1.074	1.34	1.753	2.131	2.602	2.947
16	0.535	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921
17	0.534	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898
18	0.534	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878
19	0.533	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861
20	0.533	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845
21	0.532	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831
22	0.532	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819
23	0.532	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807
24	0.531	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797
25	0.531	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787
26	0.531	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779
27	0.531	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771
28	0.530	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763
29	0.530	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756
30	0.530	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750
40	0.529	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704
60	0.527	0.679	0.848	1.046	1.296	1.671	2.000	2.390	2.660
120	0.526	0.677	0.845	1.041	1.289	1.658	1.980	2.358	2.617
∞	0.524	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576

Note: The last row of the table (∞ degrees of freedom) gives the critical values for a standard normal distribution (Z), e.g., $t_{\infty,0.95} = z_{0.95} = 1.645$.

Source: U.S. Environmental Protection Agency, *Data Quality Assessment: Statistical Methods for Practitioners, EPA QA/G-96 (2006)*

Appendix 3. Critical Values for the Wilcoxon Rank-Sum Test

Table values are the largest x values such that $P(W_{rs} \le x) \le \alpha$. Therefore, significance levels, α, are approximate. If there are ties, then the test is approximate.

min(m, n)	α	max(m, n)								
		2	3	4	5	6	7	8	9	10
2	0.010	-	-	-	-	-	-	-	-	-
	0.025	-	-	-	-	-	-	0	0	0
	0.050	-	-	-	0	0	0	1	1	1
	0.100	-	0	0	1	1	1	2	2	3
3	0.010		-	-	-	0	0	0	1	1
	0.025		-	-	0	1	1	2	2	3
	0.050		0	0	1	2	2	3	4	4
	0.100		1	1	2	3	4	5	5	6
4	0.010			-	0	1	1	2	3	3
	0.025			0	0	2	3	4	4	5
	0.050			1	2	3	4	5	6	7
	0.100			3	4	5	6	7	9	10
5	0.010				1	2	3	4	5	6
	0.025				2	3	5	6	7	8
	0.050				4	5	6	8	9	11
	0.100				5	7	8	10	12	13
6	0.010					3	4	6	7	8
	0.025					5	6	8	10	11
	0.050					7	8	10	12	14
	0.100					9	11	13	15	17
7	0.010						6	7	9	11
	0.025						8	10	12	14
	0.050						11	13	15	17
	0.100						13	16	18	21
8	0.010							9	11	13
	0.025							13	15	17
	0.050							15	18	20
	0.100							19	22	25
9	0.010								14	16
	0.025								17	20
	0.050								21	24
	0.100								25	28
10	0.010									13
	0.025									23
	0.050									27
	0.100									32

Source: U.S. Environmental Protection Agency, *Data Quality Assessment: Statistical Methods for Practitioners, EPA QA/G-96 (2006)*

Appendix 3. Critical Values for the Wilcoxon Rank-Sum Test (Continued)

Table values are the largest x values such that $P(W_{rs} \leq x) \leq \alpha$. Therefore, significance levels, α, are approximate. If there are ties, then the test is approximate.

min(m, n)	α	max(m, n)									
		11	12	13	14	15	16	17	18	19	20
2	0.010	-	-	0	0	0	0	0	0	1	1
	0.025	0	1	1	1	1	1	2	2	2	2
	0.050	1	2	2	3	3	3	3	4	4	4
	0.100	3	4	4	4	5	5	6	6	7	7
3	0.010	1	2	2	2	3	3	4	4	4	5
	0.025	3	4	4	5	5	6	6	7	7	8
	0.050	5	5	6	7	7	8	9	9	10	11
	0.100	7	8	9	10	10	11	12	13	14	15
4	0.010	4	5	5	6	7	7	8	9	9	10
	0.025	6	7	8	9	10	11	11	12	13	14
	0.050	8	9	10	11	12	14	15	16	17	18
	0.100	11	12	13	15	16	17	18	20	21	22
5	0.010	7	8	9	10	11	12	13	14	15	16
	0.025	9	11	12	13	14	15	16	18	19	20
	0.050	12	13	15	16	18	19	20	22	23	25
	0.100	15	17	18	20	22	23	25	27	28	30
6	0.010	9	11	12	13	15	16	18	19	20	22
	0.025	13	14	16	17	19	21	22	24	25	27
	0.050	16	17	19	21	23	25	26	28	30	32
	0.100	19	21	23	25	27	29	31	34	36	38
7	0.010	12	14	16	17	19	21	23	24	26	28
	0.025	16	18	20	22	24	26	28	30	32	33
	0.050	19	21	24	26	28	30	33	35	37	39
	0.100	23	26	28	31	33	36	38	41	43	46
8	0.010	15	17	20	22	24	26	28	30	32	34
	0.025	19	22	24	26	28	31	34	36	38	41
	0.050	23	26	28	31	33	36	39	41	44	47
	0.100	27	30	33	36	39	42	45	48	51	54
9	0.010	18	21	23	26	28	31	33	36	38	40
	0.025	23	26	28	31	24	37	39	42	45	48
	0.050	27	30	33	36	39	42	45	48	51	54
	0.100	31	35	38	41	45	48	52	55	58	62
10	0.010	22	24	27	30	33	36	38	41	44	47
	0.025	26	29	33	36	39	42	45	48	52	55
	0.050	31	34	37	41	44	48	51	55	58	62
	0.100	36	39	43	47	51	54	58	62	66	70

Source: U.S. Environmental Protection Agency, *Data Quality Assessment: Statistical Methods for Practitioners, EPA QA/G-96 (2006)*

Appendix 3. Critical Values for the Wilcoxon Rank-Sum Test (Continued)

Table values are the largest x values such that $P(W_{rs} \le x) \le \alpha$. Therefore, significance levels, α, are approximate. If there are ties, then the test is approximate.

min(m, n)	α	max(m, n)									
		11	12	13	14	15	16	17	18	19	20
11	0.010	25	28	31	34	37	41	44	47	50	53
	0.025	30	33	37	40	44	47	51	55	58	62
	0.050	34	38	42	46	50	54	57	61	65	69
	0.100	40	44	48	52	57	61	65	69	73	78
12	0.010		31	35	38	52	46	48	53	56	60
	0.025		37	41	45	49	53	57	61	65	69
	0.050		42	47	51	55	60	64	68	72	77
	0.100		49	53	58	63	68	72	77	81	86
13	0.010			39	43	47	51	55	59	63	67
	0.025			45	50	54	59	63	67	72	76
	0.050			51	56	61	65	70	75	80	84
	0.100			58	63	68	74	79	84	89	94
14	0.010				47	51	56	60	65	69	73
	0.025				55	59	64	69	74	78	83
	0.050				61	66	71	77	82	87	92
	0.100				69	74	80	85	91	97	102
15	0.010					56	61	66	70	75	80
	0.025					64	70	75	80	85	90
	0.050					72	77	83	88	94	100
	0.100					80	86	92	98	104	110
16	0.010						66	71	76	82	87
	0.025						75	81	86	92	98
	0.050						83	89	95	101	107
	0.100						93	99	106	112	119
17	0.010							77	82	88	93
	0.025							87	93	99	105
	0.050							96	102	109	115
	0.100							106	113	120	127
18	0.010								88	94	100
	0.025								99	106	112
	0.050								109	116	123
	0.100								120	128	135
19	0.010									101	107
	0.025									113	119
	0.050									123	130
	0.100									135	143
20	0.010										114
	0.025										127
	0.050										138
	0.100										151

Source: U.S. Environmental Protection Agency, *Data Quality Assessment: Statistical Methods for Practitioners, EPA QA/G-96 (2006)*

Appendix 4. On-Road Heavy Duty Diesel Vehicle Conversion Factors by Model Year

Vehicle Class – HDDV8a Heavy-Duty Diesel Vehicles (33,001-60,000 lbs GVWR)			Vehicle Class – HDDV8b Heavy-Duty Diesel Vehicles (Greater than 60,000 lbs GVWR)		
Model Year	Conversion Factor (bhp-hr/mi)	Energy Consumption Factor (ECF) (bhp-hr/gal)	Model Year	Conversion Factor (bhp-hr/mi)	Energy Consumption Factor (ECF) (bhp-hr/gal)
2007	2.76	18.8	2007	3.03	20.3
2006	2.76	18.8	2006	3.03	20.2
2005	2.76	18.7	2005	3.03	20.1
2004	2.76	18.6	2004	3.03	20.0
2003	2.76	18.6	2003	3.03	19.9
2002	2.76	18.5	2002	3.03	19.8
2001	2.76	18.5	2001	3.03	19.6
2000	2.76	18.4	2000	3.03	19.5
1999	2.76	18.4	1999	3.03	19.4
1998	2.76	18.3	1998	3.03	19.3
1997	2.76	18.3	1997	3.03	19.2
1996	2.76	18.2	1996	3.03	19.1
1995	2.78	18.2	1995	3.06	19.0
1994	2.81	18.1	1994	3.09	18.9
1993	2.83	18.0	1993	3.11	18.8
1992	2.85	18.0	1992	3.14	18.7
1991	2.87	17.9	1991	3.17	18.6
1990	2.90	17.9	1990	3.20	18.5
1989	2.92	17.8	1989	3.23	18.4
1988	2.95	17.8	1988	3.26	18.3
1987	2.99	17.7	1987	3.13	18.1
1986	2.99	17.6	1986	3.13	18.0
1985	3.01	17.6	1985	3.14	17.9
1984	3.04	17.5	1984	3.14	17.8
1983	3.06	17.5	1983	3.15	17.7
1982	3.09	17.4	1982	3.15	17.6
1981	3.11	17.3	1981	3.26	17.5
1980	3.06	17.3	1980	3.33	17.4

Source: Texas Commission on Environmental Quality, *Emission Reduction Incentive Grants Program Technical Supplement No.1 – Onroad Heavy Duty Vehicles*

Appendix B

Results of t-Test Analyses

Appendix B: Results of t-Test Analyses

A) Data Received from Roehl Transport, Inc.

Exhibit 1a: Fuel Economy Measured as Fuel MPG (Includes All 12 Trucks)
Data Set Excluding Extreme Outliers Only

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Control Fleet	*Test Fleet*
Mean	6.564745227	6.368300989
Variance	0.446332437	0.259818861
Observations	72	71
Hypothesized Mean Difference	0	
df	133	
t Stat	1.978491858	
P(T<=t) one-tail	**0.024969726**	
t Critical one-tail	1.656391245	
P(T<=t) two-tail	**0.049939453**	
t Critical two-tail	1.977961236	

Exhibit 1b: Fuel Economy Measured as Fuel MPG (Includes All 12 Trucks)
Data Set Excluding All Outliers

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Control Fleet	*Test Fleet*
Mean	6.470318476	6.421333884
Variance	0.309264411	0.129272257
Observations	68	67
Hypothesized Mean Difference	0	
df	115	
t Stat	0.608636098	
P(T<=t) one-tail	**0.271983008**	
t Critical one-tail	1.658211831	
P(T<=t) two-tail	**0.543966016**	
t Critical two-tail	1.980807476	

Exhibit 1c: Fuel Economy Measured as Fuel MPG (Excludes Trucks #C6 and T6)
Data Set Excluding Extreme Outliers Only

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Control Fleet	*Test Fleet*
Mean	6.606527606	6.422531698
Variance	0.493390427	0.196626035
Observations	60	59
Hypothesized Mean Difference	0	
df	100	
t Stat	1.711621798	
P(T<=t) one-tail	**0.04503314**	
t Critical one-tail	1.660234327	
P(T<=t) two-tail	**0.09006628**	
t Critical two-tail	1.983971466	

Appendix B: Results of t-Test Analyses

Exhibit 1d: Fuel Economy Measured as Fuel MPG (Excludes Trucks #C6 and T6)
Data Set Excluding All Outliers

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Control Fleet	*Test Fleet*
Mean	6.494851006	6.443738754
Variance	0.337793425	0.148809647
Observations	56	56
Hypothesized Mean Difference	0	
df	96	
t Stat	0.548316877	
P(T<=t) one-tail	**0.292373595**	
t Critical one-tail	1.660881441	
P(T<=t) two-tail	**0.58474719**	
t Critical two-tail	1.984984263	

Exhibit 2a: Fuel Economy Measured as Driving MPG (Excludes Trucks #C6 and T6)
Data Set Excluding Extreme Outliers Only

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Control Fleet	*Test Fleet*
Mean	6.741692591	6.495459052
Variance	0.487185727	0.195084344
Observations	60	59
Hypothesized Mean Difference	0	
df	100	
t Stat	2.303535158	
P(T<=t) one-tail	**0.011659347**	
t Critical one-tail	1.660234327	
P(T<=t) two-tail	**0.023318694**	
t Critical two-tail	1.983971466	

Exhibit 2b: Fuel Economy Measured as Driving MPG (Excludes Trucks #C6 and T6)
Data Set Excluding All Outliers

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Control Fleet	*Test Fleet*
Mean	6.649085952	6.514863518
Variance	0.281224336	0.175901666
Observations	53	58
Hypothesized Mean Difference	0	
df	99	
t Stat	1.469841648	
P(T<=t) one-tail	**0.072387779**	
t Critical one-tail	1.660391157	
P(T<=t) two-tail	**0.144775558**	
t Critical two-tail	1.9842169	

Appendix B: Results of t-Test Analyses

Exhibit 3a: Speed (Excludes Trucks #C6 and T6)
Data Set Excluding Extreme Outliers Only

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Control Fleet	*Test Fleet*
Mean	49.0952381	51.25
Variance	5.06387921	8.62254902
Observations	42	52
Hypothesized Mean Difference	0	
df	92	
t Stat	-4.026454429	
P(T<=t) one-tail	**5.81303E-05**	
t Critical one-tail	1.661585397	
P(T<=t) two-tail	**0.000116261**	
t Critical two-tail	1.986086272	

Exhibit 3b: Speed (Excludes Trucks #C6 and T6)
Data Set Excluding All Outliers

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Control Fleet	*Test Fleet*
Mean	49.0952381	50.67567568
Variance	5.06387921	1.503003003
Observations	42	37
Hypothesized Mean Difference	0	
df	65	
t Stat	-3.936479157	
P(T<=t) one-tail	**0.000102014**	
t Critical one-tail	1.668635976	
P(T<=t) two-tail	**0.000204028**	
t Critical two-tail	1.997137887	

B) Data Received from Sagebrush Logistics, LLC

1) Truck Group A

Exhibit 4a: Group A Fuel Economy
Data Set Excluding Extreme Outliers Only

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Group A Control Conditions	*Group A Test Conditions*
Mean	5.201226315	5.810026143
Variance	0.247924655	0.35388027
Observations	53	82
Hypothesized Mean Difference	0	
df	124	
t Stat	-6.419654859	
P(T<=t) one-tail	**1.31396E-09**	
t Critical one-tail	1.657234971	
P(T<=t) two-tail	**2.62791E-09**	
t Critical two-tail	1.979280091	

Appendix B: Results of t-Test Analyses

Exhibit 4b: Group A Fuel Economy
Data Set Excluding All Outliers

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Group A Control Conditions	*Group A Test Conditions*
Mean	5.191959534	5.867147682
Variance	0.184348904	0.226395425
Observations	51	80
Hypothesized Mean Difference	0	
df	115	
t Stat	-8.410579303	
P(T<=t) one-tail	**6.33509E-14**	
t Critical one-tail	1.658211831	
P(T<=t) two-tail	**1.26702E-13**	
t Critical two-tail	1.980807476	

Exhibit 4c: Group A Fuel Economy
Data Set Excluding Extreme Outliers Only

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	All Truck Group Control Conditions	*Group A Test Conditions*
Mean	5.231832004	5.810026143
Variance	0.406269395	0.35388027
Observations	159	82
Hypothesized Mean Difference	0	
df	174	
t Stat	-6.975431709	
P(T<=t) one-tail	**3.05717E-11**	
t Critical one-tail	1.653658017	
P(T<=t) two-tail	**6.11434E-11**	
t Critical two-tail	1.9736914	

Exhibit 4d: Group A Fuel Economy
Data Set Excluding All Outliers

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	All Truck Group Control Conditions	*Group A Test Conditions*
Mean	5.246086672	5.867147682
Variance	0.249291988	0.226395425
Observations	152	80
Hypothesized Mean Difference	0	
df	168	
t Stat	-9.289224312	
P(T<=t) one-tail	**3.94292E-17**	
t Critical one-tail	1.653974209	
P(T<=t) two-tail	**7.88585E-17**	
t Critical two-tail	1.974185153	

Appendix B: Results of t-Test Analyses

2) Truck Group B

Exhibit 5a: Group B Fuel Economy
Data Set Excluding Extreme Outliers Only

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Group B Control Conditions	*Group B Test Conditions*
Mean	5.457944946	5.644615465
Variance	0.232789003	0.313906911
Observations	55	85
Hypothesized Mean Difference	0	
df	127	
t Stat	-2.096819447	
P(T<=t) one-tail	**0.018996622**	
t Critical one-tail	1.656940344	
P(T<=t) two-tail	**0.037993244**	
t Critical two-tail	1.978819508	

Exhibit 5b: Group B Fuel Economy
Data Set Excluding All Outliers

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Group B Control Conditions	*Group B Test Conditions*
Mean	5.550186899	5.647395141
Variance	0.105361782	0.193074321
Observations	49	81
Hypothesized Mean Difference	0	
df	123	
t Stat	-1.443671435	
P(T<=t) one-tail	**0.075686808**	
t Critical one-tail	1.657336398	
P(T<=t) two-tail	**0.151373617**	
t Critical two-tail	1.97943866	

Exhibit 5c: Group B Fuel Economy
Data Set Excluding Extreme Outliers Only

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	All Truck Group Control Conditions	*Group B Test Conditions*
Mean	5.231832004	5.644615465
Variance	0.406269395	0.313906911
Observations	159	85
Hypothesized Mean Difference	0	
df	192	
t Stat	-5.222105766	
P(T<=t) one-tail	**2.28891E-07**	
t Critical one-tail	1.65282859	
P(T<=t) two-tail	**4.57782E-07**	
t Critical two-tail	1.972396447	

Appendix B: Results of t-Test Analyses

Exhibit 5d: Group B Fuel Economy
Data Set Excluding All Outliers

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	All Truck Group Control Conditions	*Group B Test Conditions*
Mean	5.246086672	5.647395141
Variance	0.249291988	0.193074321
Observations	152	81
Hypothesized Mean Difference	0	
df	182	
t Stat	-6.326519567	
P(T<=t) one-tail	**9.465E-10**	
t Critical one-tail	1.653269024	
P(T<=t) two-tail	**1.893E-09**	
t Critical two-tail	1.973084036	

3) Truck Group C

Exhibit 6a: Group C Fuel Economy
Data Set Excluding Extreme Outliers Only

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Group C Control Conditions	*Group C Test Conditions*
Mean	5.041369543	5.519393599
Variance	0.284117396	0.340681763
Observations	46	145
Hypothesized Mean Difference	0	
df	82	
t Stat	-5.17698882	
P(T<=t) one-tail	**7.88299E-07**	
t Critical one-tail	1.663649185	
P(T<=t) two-tail	**1.5766E-06**	
t Critical two-tail	1.989318521	

Exhibit 6b: Group C Fuel Economy
Data Set Excluding All Outliers

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	Group C Control Conditions	*Group C Test Conditions*
Mean	5.041369543	5.507645876
Variance	0.284117396	0.258884541
Observations	46	142
Hypothesized Mean Difference	0	
df	73	
t Stat	-5.213259617	
P(T<=t) one-tail	**8.3125E-07**	
t Critical one-tail	1.665996224	
P(T<=t) two-tail	**1.6625E-06**	
t Critical two-tail	1.992997097	

Appendix B: Results of t-Test Analyses

Exhibit 6c: Group C Fuel Economy
Data Set Excluding Extreme Outliers Only

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	All Truck Group Control Conditions	*Group C Test Conditions*
Mean	5.231832004	5.519393599
Variance	0.406269395	0.340681763
Observations	159	145
Hypothesized Mean Difference	0	
df	302	
t Stat	-4.106061203	
P(T<=t) one-tail	**2.59294E-05**	
t Critical one-tail	1.649914828	
P(T<=t) two-tail	**5.18587E-05**	
t Critical two-tail	1.967850163	

Exhibit 6d: Group C Fuel Economy
Data Set Excluding All Outliers

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	All Truck Group Control Conditions	*Group C Test Conditions*
Mean	5.246086672	5.507645876
Variance	0.249291988	0.258884541
Observations	152	142
Hypothesized Mean Difference	0	
df	290	
t Stat	-4.444578982	
P(T<=t) one-tail	**6.2748E-06**	
t Critical one-tail	1.650124931	
P(T<=t) two-tail	**1.25496E-05**	
t Critical two-tail	1.968177834	

4) All Truck Groups

Exhibit 7a: Fuel Economy Comparison, All Truck Groups
Data Set Excluding Extreme Outliers Only

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	All Truck Group Control Conditions	*All Truck Group Test Conditions*
Mean	5.231832004	5.63736262
Variance	0.406269395	0.332664381
Observations	159	311
Hypothesized Mean Difference	0	
df	292	
t Stat	-6.735669884	
P(T<=t) one-tail	**4.33485E-11**	
t Critical one-tail	1.650088711	
P(T<=t) two-tail	**8.6697E-11**	
t Critical two-tail	1.968121344	

Appendix B: Results of t-Test Analyses

Exhibit 7b: Fuel Economy Comparison, All Truck Groups
Data Set Excluding All Outliers

t-Test: Two-Sample Assuming Unequal Variances - α = 0.05		
	All Truck Group Control Conditions	*All Truck Group Test Conditions*
Mean	5.246086672	5.639899939
Variance	0.249291988	0.248982034
Observations	152	303
Hypothesized Mean Difference	0	
df	302	
t Stat	-7.937135666	
P(T<=t) one-tail	**2.04453E-14**	
t Critical one-tail	1.649914828	
P(T<=t) two-tail	**4.08905E-14**	
t Critical two-tail	1.967850163	